acq. Sept. 8/13

A

W. Hawthorne Unwin

PRESIDENT.

(THE) INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1915. v. 1

JANUARY–JUNE.

PUBLISHED BY THE INSTITUTION,
STOREY'S GATE, ST. JAMES'S PARK, LONDON, S.W.

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1915.

JANUARY–JUNE.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)
Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)
Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)
John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)
James Kennedy, 1860. (*Deceased* 1886.)
The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)
Robert Napier, 1863–65. (*Deceased* 1876.)
John Ramsbottom, 1870–71. (*Deceased* 1897.)
Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)
Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)
John Robinson, 1878–79. (*Deceased* 1902.)
Edward A. Cowper, 1880–81. (*Deceased* 1893.)
Percy G. B. Westmacott, 1882–83.
Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)
Jeremiah Head, 1885–86. (*Deceased* 1899.)
Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)
Charles Cochrane, 1889. (*Deceased* 1898.)
Joseph Tomlinson, 1890–91. (*Deceased* 1894.)
Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)
Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.
E. Windsor Richards, 1896–97.
Samuel Waite Johnson, 1898. (*Deceased* 1912.)
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900. (*Deceased* 1913.)
William H. Maw, LL.D., 1901–02.
J. Hartley Wicksteed, 1903–04.
Edward P. Martin, 1905–06. (*Deceased* 1910.)
T. Hurry Riches, 1907–08. (*Deceased* 1911.)
John A. F. Aspinall, M.Eng., 1909–10.
Edward B. Ellington, 1911–12. (*Deceased* 1914.)
Sir H. Frederick Donaldson, K.C.B., 1913–14.

The Institution of Mechanical Engineers.

OFFICERS.

1915.

PRESIDENT.

W. Cawthorne Unwin, LL.D., F.R.S., ... London.

PAST-PRESIDENTS.

John A. F. Aspinall, M.Eng., ... Manchester.
Sir H. Frederick Donaldson, K.C.B., ... Woolwich.
Sir Alexander B. W. Kennedy, LL.D., F.R.S., ... London.
William H. Maw, LL.D., ... London.
E. Windsor Richards, ... Caerleon.
Percy G. B. Westmacott, ... Ascot.
J. Hartley Wicksteed, ... Leeds.

VICE-PRESIDENTS.

William H. Allen, ... Bedford.
Henry Davey, ... Ewell.
Edward Hopkinson, D.Sc., ... Manchester.
J. Rossiter Hoyle, ... Sheffield.
Michael Longridge, ... Manchester.
Mark H. Robinson, ... London.

MEMBERS OF COUNCIL.

Archibald Barr, D.Sc., ... Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S., ... London.
Dugald Clerk, D.Sc., F.R.S., ... London.
Sir A. Trevor Dawson, ... London.
John Dewrance, ... London.
Sir J. Alfred Ewing, K.C.B., LL.D., F.R.S., ... London.
Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S.,........ Sheffield.
Charles Hawksley,......................... London.
H. S. Hele-Shaw, LL.D., D.Sc., F.R.S., ... London.
Alfred Herbert, ... Coventry.
George Hughes, ... Horwich.
Henry A. Ivatt, ... Hayward's Heath.
Robert Matthews, ... Manchester.
Donald B. Morison,......................... Hartlepool.
Sir Gerard A. Muntz, Bart., ... Birmingham.
Eng. Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S.,.. London.
William H. Patchell, ... London.
Walter Pitt, ... Bath.
Vincent L. Raven, ... Darlington.
Captain H. Riall Sankey, R.E., ret.,................. London.
Wilson Worsdell, ... Ascot.

HON. TREASURER.

F. H. Norwood.

AUDITOR.

Raymond Crane, F.C.A.

SECRETARY.

Edgar Worthington,
The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W.
Telegraphic Address:—*Mech, Parl, London.* Telephone:—*Victoria,* 4564.

The Institution of Mechanical Engineers.

PROCEEDINGS.

ANNUAL REPORT OF THE COUNCIL

FOR THE YEAR 1914.

The Council has pleasure in presenting to the members at the Sixty-Eighth Annual General Meeting the following Report of the progress and work of the Institution during the year.

The changes which have taken place in the roll during 1914 are shown in the following tabulated statement:—

	Hon. M.	M.	A.M.	A.	G.	Totals.	
Totals at 31st December 1913	7	2,694	2,916	54	675		6,346
Elected	—	51	224	2	53		
Reinstated . . .	—	1	1	—	—		
Transferred . . .	—	65	—	—	—		
Total additions during 1914	—	117	225	2	53	397	
Deceased	1	42	17	—	2		
Resigned	—	31	19	4	26		
Erased	—	14	31	—	18		
Graduates elected Associate Members .	—	—	—	—	39		
Graduates retired under By-law 3. . .	—	—	—	—	32		
Elections voided . .	—	—	1	—	1		
Transferred . . .	—	—	65	—	—		
Total deductions during 1914	1	87	133	4	118	343	
Net alterations during 1914	−1	+30	+92	−2	−65		+54
Totals at 31st December 1914	6	2,724	3,008	52	610		6,400

His Majesty the King has conferred honours upon the following Members of the Institution :—a Baronetcy upon Mr. William Beardmore, and a Knighthood upon Mr. John F. C. Snell.

The following Deceases of members of the Institution were reported during the year :—

1888. Ashby, George
1892. Atkinson, James
1901. Banister, Alan Neville
1872. Bayliss, Thomas Richard
1902. Blyth, Ernest B. (*A.M.*)
1884. Bryan, William B.
1913. Cann, Charles Edwyn (*A.M.*)
1888. Chapman, Arthur
1883. Chrimes, Charles E. (*A.*)
1878. Colyer, Frederick
1896. Conaty, George
1899. Coveney, William Charles
1909. Doxford, Arthur (*A.M.*)
1878. Eckart, William Roberts
1908. Ednie, John (*A.M.*)
1875. Ellington, Edward Bayzand (*Past-President*)
1906. Evans, John
1899. French, Arthur H. (*A.M.*)
1880. Gresham, James
1902. Griffiths, Harold (*A.M.*)
1897. Haldane, John Wilton C.
1903. Hall, Joseph
1883. Hardy, John George
1908. Hart-Davis, Hugh V. (*A.M.*)
1878. Harwood, Robert
1891. Hogarth, Thomas Oswald
1877. Hunter, Walter
1871. Jones, Charles Henry
1901. Keast, James C. (*A.M.*)
1892. Kensington, Frederick
1877. Kirk, Henry
1899. Kirkaldy, William George
1910. Law, Horace C. (*A.M.*) (*Deceased* 1913)
1891. Lindsay, William Robertson
1856. Longridge, Robert Bewick
1883. Macbeth, Norman
1903. Marks, Alfred Pally (*A.M.*)
1909. Marsh, Harry Evelyn (*A.M.*)
1859. Marten, Edward Bindon
1878. Menier, Henri (*Deceased* 1913)
1896. Merrifield, Leonard Lancaster
1884. Merthyr, The Rt. Hon. Lord, G.C.V.O.
1904. Newall, James Maurice
1897. Pearce, Thomas
1903. Pearson, Harry (*A.M.*)
1909. Pritchard, Philip Morris
1879. Ridley, J. Cartmell
1881. Sanders, Henry Conrad
1874. Sauvée, Albert
1914. Schneider, Lieut. Herbert Hugo (*A.M.*)
1900. Smith, Montague Howard
1883. Sutton, Joseph Walker
1884. Swan, Sir Joseph W., F.R.S.
1900. Venning, Eng. Lt.-Commander Thomas A., R.N. (*A.M.*)
1888. Waister, William Henry
1881. Warburton, J. Seaton
1890. Webster, John James
1912. Yates, Richard C. C. (*A.M.*)

Of these, Mr. Ellington was elected a Member of Council in 1898, a Vice-President in 1903, and President in 1911 and 1912; Mr. Marten was elected a Member of Council in 1885, and

was a Vice-President 1892–94; and Lord Merthyr (then Sir William Thomas Lewis, Bart.) was elected a Member of Council in 1901, and was a Vice-President 1905–1914.

The Institution regrets the loss, through the War, of Eng. Lt.-Commander T. A. Venning, *Associate Member*, who went down in H.M.S. "Pathfinder," Lieutenant H. H. Schneider, *Associate Member*, and three Graduates, viz., Mr. R. D. McGroarty, Mr. R. M. C. McNaughton, and Lieutenant H. I. Vandell.

The Accounts for the year ended 31st December 1914 are submitted (*see* pages 18 to 24), having been duly certified by Mr. Robert A. McLean, F.C.A., the Auditor appointed by the members at the last Annual General Meeting.

The total revenue for the year 1914 was £16,970 15*s.* 8*d.*, while the expenditure during the same period was £15,521 9*s.* 0*d.* Deducting £399 Entrance Fees, and £84 Life Compositions (which are credited to Capital), a balance of £966 6*s.* 8*d.* remains. The financial position of the Institution at the end of the year is shown by the Balance Sheet. The total investments and other assets amount to £125,549 7*s.* 10*d.*, and, deducting therefrom the £34,025 of debentures, a temporary loan of £8,000, and other liabilities, including the sum set aside for the Leasehold and Debenture Redemption Fund, the capital of the Institution amounts to £69,273 5*s.* 4*d.* The certificates of all securities have been duly verified by the Finance Committee and the Auditor.

A Pensions Contingencies Fund has been opened for possible expenditure in connexion with the Institution Staff.

Mr. Charles Hawksley, *Member of Council*, has transferred to the Institution the following Stocks to form the Capital of the Thomas Hawksley Fund :—

£700 Lowestoft Water and Gas Company, 4% Debenture Stock.

£1,300 Southend Waterworks Company, 4% Perpetual Debenture Stock.

Mr. Hawksley also kindly sent to the Institution a sum of £637 13*s.* 4*d.*, representing the interest on these Stocks from 12th July 1907, the centenary of the birth of his Father, Mr. Thomas Hawksley, *Past-President.* The Fund has been put upon trust, and the Declaration, sealed by the Institution, is appended hereto (page 25). This provides for the periodical delivery of the "Thomas Hawksley" Lecture, and the periodical award of a "Thomas Hawksley" Gold Medal, with or without a Premium.

By special request, Mr. Ellington kindly repeated his first "Thomas Hawksley" Lecture in Birmingham, Leeds, Liverpool, and Nottingham, during the months of January and February.

An invitation to deliver the "Thomas Hawksley" Lecture, 1914, was accepted by Mr. William B. Bryan, *Member*, who chose for his subject "Pumping and other Machinery for Waterworks and Drainage." Arrangements were made for the Lecture, with lantern illustrations, to be given at the Institution on 30th October, but owing to the sudden death of Mr. Bryan on 27th October, the delivery of the Lecture (which was already in type) had to be postponed. On 4th December, however, Mr. Bernard W. Bryan, *Member*, kindly delivered his Father's Lecture at the Institution, and at the request of the local members subsequently repeated it in Manchester and Birmingham. The Lecture has been published in the Proceedings (Proceedings 1914, page 811).

The first Awards of the "Thomas Hawksley" Gold Medal, for the best Papers published in the Proceedings of 1913 and 1914 respectively, have been made as follows:—

1913: To Mr. Robert S. Whipple, for his Paper on "Modern Methods of Measuring Temperature" (Proceedings 1913, page 717).

1914: To Professeur Edouard Sauvage, *Member*, for his Paper on "Recent Development of Express Locomotives in France" (Proceedings 1914, page 383); and

To M. Anatole Mallet, for his Paper on "Compound Articulated Locomotives" (Proceedings 1914, page 429).

The design of the Medal will include a portrait of the late Mr. Thomas Hawksley.

The Institution is also indebted to Mr. Charles Hawksley for the presentation of a valuable Working Model of the 1,000-i.h.p. Oscillating Jet-Condensing Engines and Paddles of H.M.S. "Sphinx," built in 1846, which he had recently purchased from the Thames Iron Works, Shipbuilding and Engineering Company.

The fourth Award of the Water Arbitration Prize has been made to Professor A. H. Gibson, D.Sc., *Member*, for his Papers on "The Design of Volute Chambers and of Guide-Passages for Centrifugal Pumps" (Proceedings 1913, page 519), and "The Resistance to the Flow of Brine Solutions through Pipes" (Proceedings 1914, page 201). The Regulations for the fifth Award in February 1917 are printed upon page 24.

The Starley Premium Fund has been put upon Trust, and the Declaration, sealed by the Institution, is printed upon page 29. The third Award will be made in February 1917.

The Benevolent Fund, which has been incorporated for nearly a year and a half, has not increased in the way that it was hoped would be the case. Notwithstanding the special appeal made by the President, the total Donations at the end of 1914 amounted to only £5,467 towards the proposed capital sum of at least £10,000; and the Annual Subscriptions amounted to only £251. The Committee of Management has been able to make a few small grants towards the relief of necessitous cases, and urges the pressing need for an increase in the number of Donations and Subscriptions. The expenses connected with the establishment of the Fund have been defrayed by the Institution.

The Institution Examinations were held in April and October. Of the fifty-five Candidates who presented themselves, sixteen

passed the Graduateship Examination (in addition to four who passed in Section 1 only), and thirty-two passed the Associate Membership Examination. Several Candidates for the October Examinations were prevented from attending on account of the War. Prizes of the value of £5 each have been awarded to J. H. Armfield and W. M. Hambly (Associate Membership Examination), and of the value of £3 to H. Gissel (Graduateship Examination), for the excellence of their Papers. The Questions have been printed in pamphlet form.* Three additions have been made to the Exempting Examination lists.

The work of the Alloys Research Committee has been progressing at the National Physical Laboratory, but one of the Assistants dealing with the research has been called out on active service in connexion with the War. The systematic study of the ternary alloys of aluminium with zinc and copper has been extended to include all the aluminium rich alloys containing up to 45 per cent. of zinc and 20 per cent. of copper. Considerable progress has been made with the research on the supposed disintegration of light alloys, and the corrosion tests on tensile test-pieces have been carried further at Portsmouth Dockyard. It is expected that the Eleventh Report will be ready for presentation during 1915.

The results of the research, under the direction of Professor J. O. Arnold, D.Met., F.R.S., at Sheffield, and Professor A. A. Read, M.Met., at Cardiff, were presented for discussion at the March Meeting, in the form of a Paper entitled "The Chemical and Mechanical Relations of Iron, Tungsten and Carbon, and of Iron, Nickel and Carbon." Further research has been made at Sheffield and Cardiff on the carbides of cobalt and molybdenum, and a Paper entitled "The Chemical and Mechanical Relations of Iron, Cobalt and Carbon," containing the results of the cobalt portion of the

* To be obtained from Messrs. Wm. Clowes and Sons, 31 Haymarket, London, S.W., price 1*s*. each (by post 1*s*. 1*d*.).

research, will be presented for discussion at an early date. The molybdenum portion of the research is well advanced, and will shortly be completed in all its branches at Sheffield, since Dr. Read and his Research Assistant at Cardiff will be engaged in military duties till the termination of the war.

The Refrigeration Research Committee, under the Chairmanship of Sir J. Alfred Ewing, K.C.B., LL.D., F.R.S., *Member*, met on several occasions during the year. Their First Report was presented and discussed at the October Meeting. It recommended a definite standard for the practical rating of refrigerating machines, depending on the actual performance between specified limits of temperature. It also prescribed an ideal cycle with which the actual performance of a refrigerating machine of the vapour-compression type could be compared, just as the performance of a steam-engine is compared with the ideal "Rankine Cycle." The Report is illustrated by three large ϕ I Charts for carbon dioxide, ammonia, and sulphur dioxide respectively, and is accompanied by Appendixes by the Chairman and Professor C. Frewen Jenkin, *Member*. The Committee has been authorized by the Council to carry out experiments with the object of supplying data which are not now available regarding the physical properties of the substances used in refrigeration.

The Wire Ropes Research Committee appointed in 1913 has held three Meetings under the Chairmanship of Mr. Walter Pitt, *Member of Council*. A schedule of forty questions relating to the actual life-history of a wire rope has been prepared, and copies issued to representative large users of wire ropes, resulting in over two hundred life-histories being received for the consideration of the Committee. Thirty-four sample portions of rope, worn and unworn, have also been received. It is hoped that the study of these data will indicate a useful direction for carrying out some tests upon a specially designed oscillating machine which is now under the consideration of the Committee.

As a consequence of the Paper on "Theory and Experiment in the Flow of Steam through Nozzles," by Professor James B. Henderson, D.Sc. (Proceedings 1913, page 253), a Research Committee, with Captain H. Riall Sankey, *Member of Council*, as Chairman, was appointed, with the following reference: "To report upon what experiments relating to 'The Action of Steam passing through Nozzles and Steam Turbines' could with advantage be undertaken." A large number of abstracts and other data have been prepared and considered by the Committee, which has reported that experiments on the subject are desirable. This report has been accepted by the Council, and the Committee has been re-appointed to carry out the research on the lines suggested. An offer from the Brush Electrical Engineering Company, to lend a three-flow condenser for experimental purposes, has been accepted with thanks.

A Research Committee was appointed to report on "A Hardness Test for Hardened Journals and Pins." This Committee, under the Chairmanship of Dr. W. Cawthorne Unwin, F.R.S., *Vice-President*, has considered the known methods of testing for hardness by scratch, rebound, indentation, and abrasion, and has obtained, from various manufacturers of steel balls and others, particulars of their individual practice. Some tests have been made by Dr. T. E. Stanton, F.R.S., on specimens of steel supplied by Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S., *Member of Council*, and other experiments are under consideration.

The proposal to form a General Engineering Research Committee was discussed in February at a Conference of the Council, with representatives of Universities, Scientific Societies, and large British Engineering Firms. An Advisory Committee, appointed to prepare a scheme for the co-ordination of research, is obtaining from manufacturers and others concerned their views on the subject.

Shortly after the outbreak of the War in August, several offers of special services were received from members, and were

forwarded by the President to the War Office. A proposal that the Institutions of Civil, Mechanical, and Electrical Engineers should raise an Infantry Battalion from among their members was being considered, when an invitation was received from the Admiralty for members of the three Institutions to enlist in the Engineer Unit of the new Royal Naval Division. This Unit of 500 men was completed at the end of September, when the event was celebrated in Camp at Ringwould, near Dover. A set of band instruments was presented to the Unit by the Councils of the three Institutions, and representatives were appointed to watch the interests of those who had joined the Corps.

An invitation was received from the War Office for the nomination of a number of members of the Institution for inclusion with the list of candidates for temporary Commissions in the Royal Garrison Artillery. Twenty-one candidates were selected by the Council, in conjunction with Major-General R. M. Ruck, C.B., R.E., and have been recommended for Commissions.

The Council also placed the principal rooms of the Institution at the disposal of the Old Public Schools and University Men's Force on 15th to 17th September, for purposes of examination and enlistment.

Shortly after the inauguration of the National Relief Fund, the President, on behalf of the Council and members, addressed a letter to H.R.H. The Prince of Wales, offering the use of the Top Floor of the new building for the purposes of the Fund. The offer was warmly accepted by His Royal Highness, and the premises are now in the occupation of H.M. Office of Works, and are being devoted to work in connexion with the objects of the Fund.

Towards the end of the year, H.M. Office of Works applied to the Institution for the accommodation of a Committee connected with the War. The Council gladly consented to place the whole of the Third Floor of the Institution at the disposal of the Government for the period of the War, at a reasonable rent. This arrangement will, for the time being, involve giving up two of the rooms hitherto used occasionally by the members.

As an outcome of the informal conference with members in the Manchester district, referred to in the last Annual Report, arrangements have been completed which enable members to hold Meetings in various provincial centres for continuing the discussions on Papers presented at the usual monthly Meetings at the Institution. With the announcement of each Meeting in London, an opportunity is given for any member to apply for a local Meeting to be held for the further discussion of the Paper. If sufficient requests are received from any local centre, arrangements are made for a Meeting to be held within a few days of the London Meeting. In this way the Report of the Refrigeration Research Committee was read in Manchester shortly after its presentation in London; and in November another Meeting was held in the same City to discuss Mr. Stoney's Paper on "The Effect of Vacuum in Steam-Turbines." At each of these Meetings the attendance was about a hundred.

In June appeared the first number of the Institution Journal, which has been issued monthly since October. Part I of each Journal consists of a *résumé* of the Paper to be presented at the ensuing Meeting, together with Institution notices and other matters of interest to the members. Being only of ephemeral interest, it will probably not be retained permanently. Part II contains the complete Paper presented at the preceding Meeting, together with the Discussions, any Papers accepted for publication, and other matter which was formerly included in the Proceedings. After the close of 1914, Part II will constitute the Proceedings as hitherto published. Arrangements have been made by which members may, on payment of 7*s.* 6*d.* at the beginning of each year, receive, in addition to the Journal, the complete Proceedings, bound in half-yearly volumes, each containing an Index. By the introduction of the monthly Journal it is hoped that members will be put more closely in touch with the Institution and its work.

A proposal for co-operation between the Engineering and Technical Societies in the Manchester district, primarily for providing a common meeting room and library in Manchester, received the sympathetic consideration of the Council, who

appointed representatives from the Council to assist in furthering the proposal.

It has been decided that the balance (about £450) of the funds subscribed for the erection in Westminster Abbey of the Memorial Window to the late Lord Kelvin, *Honorary Life Member*, should be devoted to the establishment of a Kelvin Gold Medal, to be awarded triennially, as a mark of distinction in engineering work or investigation, by the Presidents for the time being of eight leading British Engineering Institutions.

In response to an application from the Board of Education for assistance in the preparation of a Memorandum on the Teaching of Engineering in Evening Technical Schools, the Council appointed a representative Committee, who went into the matter in great detail. Their criticisms, opinions and suggestions upon the draft Memorandum were communicated to the Board, together with an offer of a Conference, if the Board thought it desirable.

An application from the Board of Trade, for observations upon a suggested amendment of the Rule for ascertaining the Nominal Horse-Power for Marine Engines, has received attention.

The Council has been glad to accede to the request of Professor H. V. Hubert, President of the Scientific Committee of the Liége Association of Engineers, and of Baron Edgar Forgeur, Secretary of the Association, that Members of the Association who are temporarily resident in this country might make use of the Institution Library.

Monthly Meetings were held throughout the year, with the exception of May, June, August and September. These Meetings were occupied with the reading and discussion of the following Papers:—

Commercial Tests of Internal-Combustion Engines; by W. A. Tookey, *Member*.

Some Modern Methods of Welding; by Thomas T. Heaton, *Member*.

The Chemical and Mechanical Relations of Iron, Tungsten, and Carbon, and of Iron, Nickel, and Carbon; by Professor J. O. Arnold, D.Met., F.R.S., and Professor A. A. Read, M.Met.

Application of Electrical Driving to Existing Rolling Mills; by L. Rothera.

Recent Development of Express Locomotives in France; by Professor Edouard Sauvage, *Member*.

Compound Articulated Locomotives; by Anatole Mallet.

Signalling on Railway Trains in Motion; by A. Sartiaux, F. Lancrenon, A. Herdner, A. Claveille, L. Maréchal, and E. Solacroup.

The New Niclausse High-Duty Marine Type Boiler; by Jules Niclausse.

Development of Internal-Combustion Engines for Marine Purposes; by M. Drosne.

Balancing of Internal-Combustion Engines; by H. F. Fullagar.

Improvements in Motor-Lorries: Self-Loading; also Driving and Steering through all Wheels; by Eugène Brillié.

Report of the Refrigeration Research Committee.

The Effect of Vacuum in Steam-Turbines; by G. Gerald Stoney, F.R.S., *Member*.

Audible and Other Cab Signals on British Railways; by W. C. Acfield, *Member*; Leon P. Lewis; Vincent L. Raven, *Member*; W. A. Stanier, *Member*; and W. Willox.

The following Papers were accepted for publication in the Proceedings with discussion in writing:—

The Discharge of Steam through Nozzles; by Dr. William E. Fisher.

The Theory of the Flow of Gases through Nozzles; by J. G. Stewart.

The following Papers were selected for publication in the Proceedings without discussion:—

The Resistance to the Flow of Brine Solutions through Pipes; by Professor A. H. Gibson, D.Sc., *Member*.

Jigs and Fixtures; by H. J. Thompson, *Associate Member*.

Shipbuilding and Shipyard Practice; by W. J. Drummond, *Graduate*.

The Summer Meeting was held in Paris on 7th–11th July, the Meeting Hall and other rooms of the Société des Ingénieurs Civils de France, having been cordially placed at the disposal of the Institution. The Council desires to record its obligations to Mr. William Hanning, *Member*, President of the British Chamber of Commerce in Paris, M. Armand de Dax, Secretary of the Société des

Ingénieurs Civils, and others, for their assistance in connexion with the Meeting. Visits were arranged to various Works and places of interest in Paris and neighbourhood, Lille, Valenciennes, Douai, Roubaix, Croix, Le Havre, and Rouen; also to the Castles of Chantilly, Pierrefonds and Compiègne. The attendance at the Meeting was 130 members, 26 visitors, and 54 ladies.

The Council desires to thank those members and others who have made presentations to the Library. A complete list of additions will be found on pages 31–51. An "Author" Index of the books, pamphlets, etc., has been completed, and placed in a suitable cabinet for use by members. The preparation of a "Subject" Index is in hand. The possibility of combining these in a printed Catalogue is under consideration. To meet the wishes of certain members unable to visit the Library during the day, arrangements were announced on various occasions to all members that the Library would be kept open till nine o'clock every Monday evening during the months of March–May, and October–December. So little advantage has been taken of these additional facilities that it has been decided to discontinue the experiment. The former practice of keeping the Library open until eight o'clock on the evenings of the Graduates' and Ordinary Meetings is retained. During the year 653 books were lent to members resident in London and the Provinces, and 121 searches for special information were made for members.

The Institution during the year has been represented on the following Organizations:—

Courts of the Universities of Bristol, Liverpool, and Sheffield.
Governing Body of the Imperial College of Science and Technology.
General Committee of the Royal Society for administering the Government Grant for Scientific Investigations.
National Physical Laboratory.
Engineering Standards Committee, and Sectional Committees.
School of Metalliferous Mining (Cornwall).
London Committee of the University of Hong Kong.
Napier Tercentenary Celebration Committee, 1914.

Congress of the Royal Sanitary Institute, Blackpool, 1914.
International Congress of Mining, Metallurgy, Engineering and Economic Geology, London, 1915. (*Postponed sine dic.*)
Lord Kelvin Memorial Committee.
Sir William White Memorial Committee.
Committee to consider the question of the need of some special training for Road Engineers.
Advisory Committee of the City and Guilds of London Institute, to consider the Institute's syllabus of instruction and examination in Mechanical Engineering.
Nomenclature Committee, constituted by the Institute of Metals.

In addition to the loan of rooms to H.M. Office of Works, in connexion with the National Relief Fund, and to the Old Public Schools and University Men's Force, the Council has been glad to grant permission for the following kindred Societies to hold Meetings in the Institution House:—

Benevolent Fund of the Institution of Mechanical Engineers.
British Commercial Gas Association.
Engineering Standards Committee.
Institute of Metals.
Institution of Automobile Engineers.
Institution of Gas Engineers.

The Calcutta and District Section of the Institution, which in May numbered 90 Members, held four Meetings during the Session 1913–14. At one of these, a Paper entitled "Jigs and Fixtures," by H. J. Thompson, *Associate Member*, of Calcutta, was read and discussed. This Paper has been selected by the Council for publication (Proceedings, Part 4, 1914). At another Meeting Mr. G. B. Williams, *Member*, the Chairman of the Section, read Mr. Ellington's "Thomas Hawksley" Lecture, which was illustrated by the original lantern slides.

Visits were made to the following Works:—

Sara Ghat Bridge, in course of construction over the Lower Ganges.
East Indian Railway, Carriage and Wagon Works, at Lilloah.
Calcutta Port Commissioners' new Sand-Suction Dredger "Balari."

The Annual Dinner of the Section was held on 21st February, and was attended by 135 Members and guests. With a view to

providing a permanent and suitable home for the Section, a Building Fund has been started by the Committee. A further grant of £25 (towards the expenses of the Section in 1914) has been made from the Institution funds. Mr. J. H. H. Rolfe, *Member*, and Mr. R. H. Morris, *Member*, have continued to act as Joint Honorary Secretaries and Treasurers.

The Graduates' monthly Meetings during the Session 1913–14 were occupied by the reading and discussion of the following Papers by Graduates :—

The Vacuum Automatic Brake ; by Charles H. Adams.
Modern Methods of Steam Raising ; by R. D. McGroarty.
Shipbuilding and Shipyard Practice ; by W. J. Drummond.
The Arrangement of Modern Engineering Shops ; by H. C. Armitage.
Condensing Plants ; by Ralph Jackson.
Chains for Power Transmission ; by W. Clewes Garner.
Steel Tyres as Applied to Railway Practice ; by W. J. Maize.

Prizes for the best Papers have been awarded by the Council to Mr. Drummond and Mr. Jackson, and the Paper by the former has been accepted for publication in the Proceedings (Proceedings, Part 4, 1914).

At the February Meeting, Mr. Michael Longridge, *Vice-President*, delivered an illustrated Lecture on "Breakdowns of Stationary Engines," which has been printed in the Proceedings (Proceedings 1914, page 67).

Eight Visits were made to Works in London and neighbourhood. The average attendances of Graduates were 28 at their Meetings and 14 at the Visits. A copy of the Rules of the Graduates' Association was issued to each Graduate in November.

The Engineering Societies of the Universities of Birmingham, Bristol, Edinburgh, Glasgow, Liverpool, and Manchester, and of the University College of South Wales and Monmouthshire, and Armstrong College, Newcastle-on-Tyne, again kindly invited the Graduates residing in those neighbourhoods to attend the Meetings of their respective Societies during the Session.

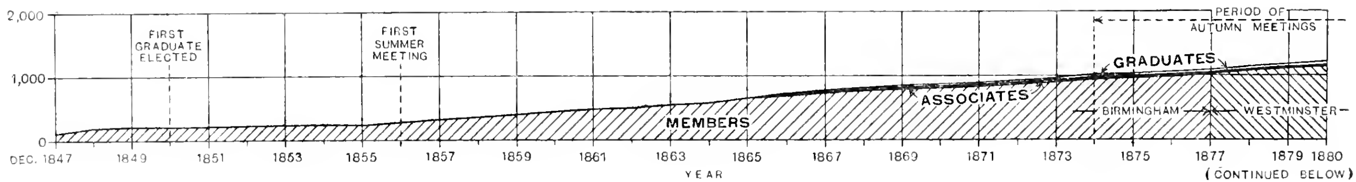
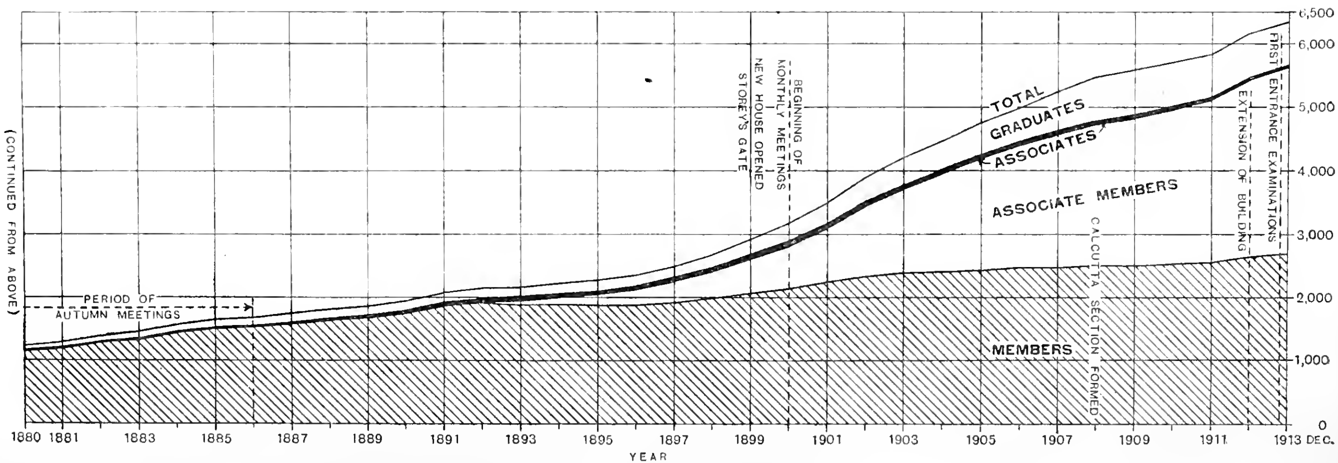


DIAGRAM SHOWING GROWTH OF THE INSTITUTION FROM 1847 TO 1913.



ACCOUNT OF REVENUE AND EXPENDITURE

AND

BALANCE SHEET FOR 1914.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£ s. d.	£ s. d.
To Expenses of Maintenance and Management—		
Salaries and Wages	4,088 13 2	
Postages, Telegrams, and Telephone	953 13 4	
Heating, Lighting, and Power	187 0 1	
Fittings and Repairs	102 13 4	
Housekeeping	176 16 8	
Incidental Expenses	113 6 0	
		5,622 2 7
,, Printing, Stationery, and Binding—		
Printing and Engraving Proceedings	2,064 1 4	
Do. Journal	244 17 4	
Stationery and General Printing	873 1 11	
Binding	121 19 1	
		3,303 19 8
,, Rent, Rates, Taxes, &c.—		
Ground Rent (Birdcage Walk)	1,112 17 2	
Do. No. 5 Princes Street	135 0 0	
Rates and Taxes	1,329 4 3	
Insurance (including National Health contributions £10 1s. 2d.)	69 17 8	
		2,646 19 1
,, Meeting Expenses—		
Printing	388 16 10	
Travelling and Incidental Expenses	213 17 6	
Reporting	70 13 10	
Translations	11 12 9	
		685 0 11
,, Reception		190 13 0
,, Dinner Expenses		132 14 8
,, Calcutta and District Section		25 0 0
,, Council Prizes		16 6 1
,, Books purchased		58 16 8
,, Law Charges		57 18 4
,, Card-Catalogue of the Library		37 0 9
,, Contributions to Napier Tercentenary Celebration and International Mining Congress		11 10 0
,, Expenses of Examinations		213 4 0
,, Expenses in connection with Research Committees		371 14 2
,, Initial expenses of the Benevolent Fund		143 4 7
,, Superannuation allowance		104 0 0
,, Depreciation on Furniture and Fittings		216 16 7
,, Debenture Interest		1,361 0 0
,, Interest on Loan		323 7 11
Total Expenditure		15,521 9 0
,, Entrance Fees, carried to Capital Account (*per contra*)		399 0 0
,, Life Compositions, carried to Capital Account (*per contra*)		84 0 0
,, Balance, being excess of Revenue over Expenditure (exclusive of value of Subscriptions in arrear), carried to Balance Sheet		966 6 8
		£16,970 15 8

FOR THE YEAR ENDED 31ST DECEMBER 1914. *Cr.*

Revenue.

	£	s.	d.
By Subscriptions for 1914	14,452	10	0
„ Subscriptions in arrear, paid in 1914	897	0	0
„ Entrance Fees for 1914	399	0	0
„ Life Compositions	84	0	0
„ Rent of Upper Floor of Institution Building	450	0	0
„ Interest, &c. (exclusive of Trust Funds)— *From Investments and Deposits at Bank*	388	16	9
„ Reports of Proceedings— *Extra Copies sold*	197	6	11
„ Examination Fees	101	17	0
„ Debenture Transfer Fees	0	5	0
	£16,970	15	8

Dr. BALANCE SHEET

	£ s. d.	£ s. d.
To 4% Debentures (1912 Issue):—		
327 *Debentures of* £100 *each*	32,700 0 0	
23 *Debentures of* £50 *each*	1,150 0 0	
7 *Debentures of* £25 *each*	175 0 0	
		34,025 0 0
,, Sundry Creditors—		
Loan from Messrs. Richard and Robert H. Williamson	8,000 0 0	
Accounts owing at 31st *Dec.* 1914	2,012 16 11	
Unclaimed Debenture Interest (coupons not presented)	298 0 1	
		10,310 17 0
,, Subscriptions paid in advance		160 0 0
,, Trust Funds (see pages 22–24), *per contra*—		
Willans Premium Fund	174 15 8	
Water Arbitration Prize Fund	538 15 4	
Bryan Donkin Fund	381 17 6	
Starley Premium Fund	451 19 2	
Thomas Hawksley Fund	2,554 10 3	
		4,101 17 11
,, Pensions Contingeneies Fund (*Investment and Interest*)		102 3 0
,, Sinking Fund set aside for Redemption of Debentures and Institution's Leasehold Property		7,576 4 7
,, Balance, being Capital of the Institution, exclusive of the Sinking Fund:—		
Balance at 31st *Dec.* 1913	67,924 6 2	
Deduct—		
Amount set aside for Pensions Contingencies Fund	100 7 6	
	67,823 18 8	
Add—		
Excess of Revenue over Expenditure for the year ended 31st *Dec.* 1914	966 6 8	
Amount received from Entrance Fees during 1914	399 0 0	
Amount received from Life Compositions during 1914	84 0 0	
		69,273 5 4
		£125,549 7 10

Signed by the following Members of the Finance Committee:—

Mark Robinson (*Chairman*). | W. H. Allen.
W. H. Maw. | H. S. Hele-Shaw.
H. Riall Sankey.

AT 31st DECEMBER 1914. Cr.

	£	s.	d.	£	s.	d.
By Cash (exclusive of Trust Funds)—						
In Union of London and Smiths Bank—						
Deposited at Interest	1,800	0	0			
On Current Account	463	16	9			
,, Sinking Fund Account	142	12	7			
	2,406	9	4			
In the Secretary's hands	84	9	10			
				2,490	19	2
,, Amount in Union of London and Smiths Bank to meet unclaimed Debenture Interest (*coupons not presented*)				298	0	1
,, Investments (*of which £7,576 4s. 7d. has been set aside for Redemption of Debentures and the Institution's Leasehold Property, and £100 7s. 6d. for the Pensions Contingencies Fund*) . . . Cost				15,693	9	4

£	s.	d.	
5,408	0	0	*L. and N. W. Ry. 3% Debenture Stock.*
5,080	12	0	*Midland Ry. 2½% Debenture Stock.*
3,084	10	8	*Metropolitan Water (B) 3% Stock.*
2,709	3	4	*2½% Consols.*
1,586	0	0	*London County 3½% Consolidated Stock.*
800	0	0	*L. & S. W. Ry. 3% Consolidated Deb. Stock.*

No official quotations being available at 31st Dec. 1914, the actual depreciation in the value of Securities cannot be shown.

	£	s.	d.	£	s.	d.
,, Subscriptions in arrear, *not valued.*						
,, Furniture and Fittings (*less depreciation*)				1,951	10	0
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)				1,340	0	0
,, Proceedings—stock of back numbers, *not valued.*						
,, Institution House . . . Cost	60,270	2	10			
,, Princes Street Extension	39,403	8	6			
				99,673	11	4
,, Investments and Cash in Bank on account of Trust Funds (see pages 22–24), *per contra*—						
Willans Premium Fund	174	15	8			
Water Arbitration Prize Fund	538	15	4			
Bryan Donkin Fund	381	17	6			
Starley Premium Fund	451	19	2			
Thomas Hawksley Fund	2,554	10	3			
				4,101	17	11
				£125,549	7	10

I have examined the above Balance Sheet and report that I have obtained all the information and explanations I have required. In my opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of the information and explanations given to me and as shown by the Books of the Institution.

Robt. A. McLean, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

19*th January* 1915.

WILLANS PREMIUM FUND.

(*Subscribed*, 1897, *by friends of the late P. W. Willans, to commemorate the services he rendered to Engineering and Electrical Science.*)

(Under a Joint Trust with the Institution of Electrical Engineers.)

Investment £159 8*s.* 5*d.* of India 3% Stock . . . . *cost* £165 5*s.* 0*d.*

Dr.	£ s. d.	*Cr.*	£ s. d.
To Balance, held in trust .	9 10 8	By Balance from 1913 . .	4 15 4
		,, Interest, 1914 . . .	4 15 4
	£9 10 8	(*No Income Tax deducted.*)	£9 10 8

See Balance Sheet.

(For Declaration of Trust, *see* Proceedings 1913, page 124.)

WATER ARBITRATION PRIZE FUND.

Presented by Sir Edward Fry and the Metropolitan Water Board, to commemorate the holding, in the Institution building, of the Court of Arbitration, 1903–5, *relating to the purchase of the Undertakings of the eight London Water Companies.*)

Investment £523 10*s.* 2*d.* of Metropolitan Water (B) 3% Stock *cost* £500 0 0

Dr.	£ s. d.	*Cr.*	£ s. d.
To Balance	38 15 4	By Balance from 1913 .	23 1 11
		,, Interest, 1914 . . .	14 15 3
		,, Income Tax refunded, 1914	0 18 2
	£38 15 4		£38 15 4

See Balance Sheet.

(For Regulations, *see* page 24.)

BRYAN DONKIN FUND.

(*Bequest*, 1909, *under the Will of the late Bryan Donkin, Vice-President* 1901–2.)

Investment £349 15*s*. 8*d*. of London County 3½% Consolidated Stock
cost £360 6*s*. 6*d*.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Balance	21	11	0	By Balance from 1913 .	9	7	1
				„ Interest, 1914 . . .	11	9	7
				„ Income Tax refunded, 1914	0	14	4
	£21	11	0		£21	11	0

See Balance Sheet.

(For Regulations, *see* page 28.)

STARLEY PREMIUM FUND.

(*Presented*, 1906, *by the J. K. Starley Memorial Committee.*)

Investment £435 8*s*. 5*d*. of London County 3½% Consolidated Stock
cost £440 7*s*. 6*d*.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Award to Col. R. E. B. Crompton, C.B. .	45	14	0	By Balance from 1913 .	42	2	2
„ Balance	11	11	8	„ Interest, 1914 . . .	14	6	2
				„ Income Tax refunded, 1914	0	17	4
	£57	5	8		£57	5	8

See Balance Sheet.

(For Declaration of Trust, *see* page 29.)

THOMAS HAWKSLEY FUND.

(*Established by Mr. Charles Hawksley, Member of Council, to commemorate the Centenary on* 12*th July* 1907 *of the birth of his Father, the late Mr. Thomas Hawksley, F.R.S., President* 1876–1877 (*died* 23 *Sept.* 1893).)

Capital—

£1,300 *Southend Waterworks Co.* 4% *Perpetual Debenture Stock* *nominal value* £1,300 0 0

£700 *Lowestoft Water and Gas Co.* 4% *Debenture Stock* *nominal value* £700 0 0

Accumulated Interest (invested)—

£420 *G. W. Ry.* 4½% *Debenture Stock* . . . . *cost* £499 14 6

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Investment . . .	499	14	6	By Balance from 1913 .	600	0	0
,, Lecturer, 1913 .	63	0	0	,, Interest, 1913, per Mr. Charles Hawksley .	37	13	4
,, Expenses at Provincial centres, 1913	14	0	8	,, Interest, 1914 . .	46	7	7
,, Lecturer, 1914 .	52	10	0				
,, Balance . . .	54	15	9				
	£684	0	11		£684	0	11

See Balance Sheet.

(For Declaration of Trust, *see* page 25.)

Water Arbitration Prize.

Regulations for the Fifth Award, to be made in February 1917.

1. The Award will be made for the best original Paper dealing with any of the following subjects:—Methods of Purification of Water for Domestic or Trade Purposes, or Description of Hydraulic Machinery, or New Investigations in Hydraulics, or New Developments in Distribution of Water for Town's Supply or Irrigation, or Advances in the Utilization of Water Power, accepted by the Council for publication with or without discussion in the

Institution Proceedings of 1915 and 1916, provided that the Paper be of sufficient merit in the judgment of the Council.

2. Papers should be sent in as soon as possible, but not later than 1st September 1916.

3. Papers should be illustrated by scale drawings, but may be accompanied by photographs, lantern-slides, and specimens.

4. Any Paper not accepted for printing in the Proceedings will be returned to the Author.

5. The Prize will have the value of about £30, and will be accompanied by a Certificate bearing the Seal of the Institution.

THOMAS HAWKSLEY FUND.

Declaration of Trust.

To all to whom these PRESENTS shall come THE INSTITUTION OF MECHANICAL ENGINEERS (hereinafter called "the Institution") send greeting.

WHEREAS Mr. Charles Hawksley, a Member of the Council of the Institution, being desirous that a special Fund should be founded to perpetuate the memory of his Father, the late Mr. Thomas Hawksley, Fellow of the Royal Society, President of the Institution of Civil Engineers 1871 and 1872, and President of the Institution 1876 and 1877 (who died on the twenty-third day of September One thousand eight hundred and ninety three), has transferred into the name of the Institution Seven hundred pounds Four per cent. Perpetual Debenture Stock of the Lowestoft Water and Gas Company and One thousand three hundred pounds Four per cent. Perpetual Debenture Stock of the Southend Water Works Company, and has also paid to the Institution in cash a sum of Six hundred pounds in lieu of interest in respect of those sums of Stock between the twelfth day of July One thousand nine hundred and seven (the Centenary of the birth of the said Thomas Hawksley) and the thirtieth day of June One thousand nine hundred and thirteen, and also the sum of Thirty seven pounds thirteen shillings and fourpence, being the interest in respect of those sums of Stock

for the half year to the thirty-first day of December One thousand nine hundred and thirteen AND the Institution has, at the request of, and after consultation with, the said Charles Hawksley, determined to hold the said Fund upon trust for the purposes hereinafter mentioned.

NOW THESE PRESENTS WITNESS that the Institution DO HEREBY DECLARE the Trusts upon which they hold the said Fund to be as follows:—

1. That the name of the Fund shall be the "Thomas Hawksley Fund," and that it shall be kept as a separate account in the books of the Institution.

2. The Institution shall hold and retain the said two sums of Debenture Stock so long as the Council for the time being of the Institution (hereinafter called "the Council") think fit, with power to sell and convert the same from time to time at the discretion of the Council, and shall invest the net proceeds of any such sale (with any additions from time to time made to the Capital of the Fund) in the name of the Institution in or upon such investments as are, or may, for the time being, be authorised under the Articles of Association of the Institution for the investment of moneys of the Institution not immediately required for its purposes, or in or upon any investments which Trustees are or may be by law authorised to invest in, with power to vary any such investments for others of a like nature.

3. That the income (including the said sums of Six hundred pounds and Thirty seven pounds thirteen shillings and fourpence in cash) derived from the said sums of Debenture Stock and investments, after payment of expenses incidental to the administration of the Fund, shall, subject as hereinafter provided, be devoted:—

(*a*) To the maintenance of a Lecture to be known as the "Thomas Hawksley" Lecture, upon some subject connected with Mechanical Engineering to be from time to time fixed by the Council, and to be delivered annually or at such other intervals not exceeding three years as the Council may from time to time prescribe (hereinafter referred to as "the prescribed period").

(*b*) To the Award by the Council annually (subject as hereinafter provided) of a "Thomas Hawksley" Gold Medal, with or without a "Thomas Hawksley" Premium in money, books or otherwise, for the best original Paper read at a General Meeting of the Institution or printed in the Proceedings of the Institution during the preceding year, Provided always that no Medal or Premium shall be awarded unless some Paper so read or printed shall, in the opinion of the Council, be deemed worthy of such Award or Awards, and that the Council shall have power, if they deem that any two such Papers read or printed in the same year have special merit, to award a Medal in respect of one Paper and a Premium in respect of the other if they think fit.

4. The Council may at their discretion arrange for the Lecture to be delivered either in London or in some other centre of Mechanical Engineering in the United Kingdom, and for it to be repeated in one or more such centres. The Lecturer shall be appointed specially for each prescribed period at which the Lecture is to be delivered, and the terms of his engagement shall be in the discretion of the Council.

5. The appropriation from time to time of the said income of the Fund between the objects named in Clause 3 hereof shall be in the discretion of the Council. And in the event of a Lecture not being delivered within any prescribed period, or of a Medal or Premium not being awarded in any year, or of any sum available or appropriated in respect of any of the said objects not being from any cause fully expended during any such period or year, the amount so available or appropriated may be utilized for the purposes of any "Thomas Hawksley" Lecture, Medal or Premium to be delivered or awarded in any succeeding period or year, or may be added to the Capital of the "Thomas Hawksley" Fund, at the discretion of the Council.

6. SUBJECT as aforesaid, the Institution and the Council respectively may from time to time adopt, make and alter such regulations and provisions, with regard to the conduct of their business respectively, and with regard to any matters in respect of which any power or duty is hereby vested in them respectively, as they may deem proper.

In witness whereof the Institution hath caused its Common Seal to be hereunto affixed this twentieth day of July One thousand nine hundred and fourteen.

The Common Seal of the Institution of Mechanical Engineers was affixed hereto in the presence of

L.S.

H. Riall Sankey, *Member of Council.*
W. H. Allen, *Member of Council.*
Edgar Worthington, *Secretary.*

Bryan Donkin Fund.

Third Award, to be made in February 1916.

1. The Bryan Donkin Award, consisting of the interest on the sum of £360 6*s*. 6*d*., shall be made triennially, beginning in 1910.

2. The grant or grants made at each Award shall be devoted to assisting original research.

3. Every three years the Council shall direct attention to the Bryan Donkin Fund, and shall announce that on a convenient date, to be fixed by them, they will be open to receive from those engaged in original research in Mechanical Engineering applications for grants in aid.

4. All applications so received shall be considered by a Committee specially appointed by the Council for that purpose, who shall make recommendations to the Council upon the apportionment of the sum available. If this Committee shall consider that none of the applications is deserving of a grant, or that the sum available is in excess of the grants which it is desirable to make, they shall so report to the Council.

5. In the event of no grant being made, or the grants made amounting to less than the sum available, the surplus shall be devoted to aiding the Research Committees of the Institution, and shall be distributed in such proportions as the Council shall decide.

Starley Premium Fund.

Declaration of Trust.

To all to whom these Presents shall come The Institution of Mechanical Engineers (hereinafter called "the Institution") send greeting.

Whereas a Fund was subscribed by voluntary contributions for the purpose of commemorating the memory and the work of the late Mr. John Kemp Starley, and it was intended that such Fund should be dealt with in a way calculated to promote the interest of Road Locomotion And whereas the Committee of the said John Kemp Starley Memorial Fund, of which Mr. Robert Todd was Chairman and Mr. Robert Turnbull Lang was Secretary, and of which Mr. Joseph Charles Parkinson, Mr. Ernest R. Shipton and Mr. Harry Smith were Members, decided to hand the Fund so collected, namely the sum of Four hundred and forty pounds seven shillings and sixpence, to the Institution, and at their request the Institution agreed to accept the same and to act as Trustees thereof on the following terms, and the said sum was accordingly paid to the Institution in the month of January 1908 and was invested in the name of the Institution in £435 8*s.* 5*d.* London County Consolidated Stock.

Now these presents witness that the Institution do hereby accordingly declare that the Trusts upon which they hold the same are as follows:—

1. That the name of the Fund shall be "The Starley Premium Fund."

2. That the amount of the Fund (with any addition from time to time made to the Capital thereof) shall be invested in the name of the Institution in such securities as Trustees are by law authorised to invest in, with power to vary.

3. That the income derived from the investments of the Fund, after payment of any expenses incidental to the administration of the Fund, shall be presented triennially in and after February 1911 as a Premium to be awarded by the Council for the time being of the Institution (hereinafter called "the Council"), for the best

original Paper dealing with "The Development of Road Locomotion" published in the Proceedings of the Institution during the previous three years PROVIDED that the Premium shall not be awarded unless a Paper of sufficient merit in the judgment of the Council shall have been so published since the preceding Award.

4. THAT in the event of no Award being made by the Council at the end of any triennial period, the amount of the Premium available for that Award shall be added to the Capital of the Fund, unless during the ensuing triennial period two Papers dealing with "The Development of Road Locomotion," and which the Council deem to be of sufficient merit, be communicated to and published in the Proceedings of the Institution, in which event the Council may, if they think fit, award two Premiums, one for each of such Papers.

5. THE Premium shall be awarded in any form which the Council from time to time determine.

6. AND the Institution, in declaring the said Trusts as aforesaid, hereby reserve and declare that the Institution and the Council respectively may, subject to the said Trusts, from time to time adopt and make and alter such regulations and provisions with regard to the conduct of their business respectively, and with regard to any matters in respect of which any power or duty is hereby vested in them respectively, as they may deem proper.

IN WITNESS whereof the Institution hath caused its Common Seal to be hereunto affixed this twentieth day of April One thousand nine hundred and fourteen.

THE COMMON SEAL of The Institution of Mechanical Engineers was hereunto affixed in the presence of

L. S.

H. F. DONALDSON, *President.*
W. H. MAW, *Past-President.*
EDGAR WORTHINGTON, *Secretary.*

LIST OF ADDITIONS TO THE LIBRARY.

BOOKS (in order received).

Farm Gas Engines, by C. F. Hirshfeld and T. C. Ulbricht.

Engineering as a Profession, by A. P. M. Fleming and R. W. Bailey.

Jigs and Fixtures, by F. H. Colvin and L. L. Haas.

Text-Book of Highway Engineering, by Professor A. H. Blanchard and H. B. Drowne.

Light, Radiation and Illumination, by Paul Högner (translated by Justus Eck).

Carburation in Theory and Practice, by R. W. A. Brewer.

Portland Cement (3rd ed.), by D. B. Butler.

Dynamo and Motor Attendants and Their Machines (7th ed.), by Frank Broadbent.

Cranes and Hoists, by Hermann Wilda (translated by Charles Salter).

Egyptian Irrigation (2 vols., 3rd ed.), by Sir W. Willcocks, K.C.M.G., and J. I. Craig (with an Introduction by Sir Hanbury Brown, K.C.M.G.); from Mr. S. W. Kershaw.

Summary of British and Foreign Patent Laws, by B. E. D. Kilburn; from the author.

A First Book of Practical Mathematics, by T. S. Usherwood and C. J. A. Trimble; from the publishers.

Studies in Water Supply, by A. C. Houston, D.Sc., M.B.; from the publishers.

The Design of Plate-Girders and Columns, by W. E. Lilly.

The Elements of Specification Writing, by Professor R. S. Kirby.

High and Low Tension Switchgear Design, by A. G. Collis.

Electrical Engineering for Mechanical and Mining Engineers, by H. J. S. Heather.

Berechnung der Kältemaschinen, by Professor P. Ostertag.

The A. B. C. Guide to Patents for Inventions, by R. E. Phillips and A. M. Flack; from Mr. R. E. Phillips.

The Maintenance of Foreshores, by Ernest Latham; from the author.

Metallurgy: Iron and Steel (1864), by John Percy, M.D., F.R.S.; from Mr. H. H. P. Powles.

Bessemer, Göransson and Mushet, by E. F. Lange; from the author.

Principles of Thermodynamics (2nd ed.), by Professor G. A. Goodenough.

Boiler-Waters: Scale, Corrosion, Foaming, by W. W. Christie.

Composition and Heat Treatment of Steel (2nd ed.), by E. F. Lake.

Rules of Management, by William Lodge.

Solenoids, Electromagnets and Electromagnetic Windings, by C. R. Underhill.

The Quadrant and Shaper of the Self-Acting Mule (2nd ed.), by W. S. Taggart; from the author.

Natural Sources of Energy, by Professor A. H. Gibson, D.Sc.; from the author.

"Hütte," Des Ingenieurs Taschenbuch (3 vols., 21st ed.).

Hydraulics and its Applications (2nd ed.), by Professor A. H. Gibson, D.Sc.; from the author.

Compressed Air Practice, by Frank Richards.

Practical Mathematics for Technical Students, Part I, by T. S. Usherwood and C. J. A. Trimble; from the publishers.

Test Papers in Elementary Algebra, by C. V. Durell, M.A.; from the publishers.

Exercises in Mathematics, by D. B. Mair, M.A.; from the publishers.

Factory Administration and Accounts, by E. T. Elbourne, with contributions by A. Home-Morton and John Maughfling; from Mr. J. E. Thornycroft.

Cane Sugar, by Noël Deerr; from Mr. C. H. Wingfield.

A Ballad of Men and other Verses, by William Blane; from the author.

An Elementary Treatise on the Calculus (4th ed.), by John Graham; from the publishers.

Baumé and Specific Gravity Tables for Liquids lighter than Water, by N. H. Freeman; from the author.

Kinematics (4th ed.), by C. W. MacCord; from Mr. S. W. Kershaw.

Well-Boring for Water, Brine and Oil (2nd ed.), by C. Isler.

Gear Cutting in Theory and Practice, by J. G. Horner.

Cams and the Principles of their Construction, by George Jepson.

Kinematics of Machinery (2nd ed.), by J. H. Barr and Professor E. H. Wood.

Taschenbuch der Luftflotten, by F. Rasch and W. Hormel.

Practical Iron Founding (4th ed.), by J. G. Horner; from the publishers.

The Gas Turbine, by Norman Davey; from the publishers.

The Scientific Determination of the Merits of Automobiles, by Dr. A. Riedler.

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ADDITION TO MUSEUM.

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ON THE STEADY FLOW OF STEAM THROUGH A NOZZLE OR THROTTLE.

By Professor H. L. CALLENDAR, M.A., LL.D., F.R.S.,
of the Imperial College of Science and Technology, London.

[*Selected for Publication only.*]

The problem of the Flow of Steam through a Nozzle or Throttle is one of considerable experimental difficulty and theoretical interest, which is still exciting attention and discussion on account of its practical importance. It is hoped that the following theoretical examination of the question, though founded on experiments made several years ago, may not be out of place at the present juncture. The author's views have been quoted by Professor Henderson and others in the course of the discussion, but a somewhat essential point of his theory has been overlooked, which appears to require further elucidation.

In the course of some experiments undertaken in conjunction with the late Professor J. T. Nicolson "On the Law of Condensation of Steam,"* in which the temperatures of steam during adiabatic expansion and compression were observed with a very sensitive platinum thermometer in the cylinder of a steam-engine, it was found that the index m of the adiabatic equation PV^m = constant was very nearly independent of the pressure and temperature, and equal to 1·30. This result, at first sight discordant with the wide variations of the specific heat shown by other experiments made

* Proceedings, Inst.C.E., 1898, Vol. cxxxi, p. 147.

at the same time, was brought into exact agreement with the variation of the specific heat by the author's theory, published shortly afterwards,* which has met with general acceptance. The temperature measurements also showed that during rapid adiabatic expansion the temperature of steam might fall appreciably below the saturation temperature, indicating a state of supersaturation in the cylinder, which was suggested at the time as a possible explanation of part, at least, of the "missing quantity." The practical importance of this state of supersaturation increases in proportion to the *rapidity* of the expansion, and becomes considerable in the case of expansion through a nozzle, where it affords an explanation of material difficulties and discrepancies. The object of the present Paper is to apply the equation for supersaturated steam to the problem, but in order to make the discussion intelligible it will first be necessary to explain exactly what is assumed in the generally accepted theory.

Steady Flow through a Nozzle or Throttle.—It follows from the conservation of mass that, when a fluid is flowing *steadily* along a pipe of variable section X, the mass-flow W, measured in lb. per hour or other convenient units, must be the same at all points of the pipe. This condition is often called the equation of continuity, and leads to the following relation between the mean velocity U and specific volume V over the cross-section X, at any point of the pipe

$$k\,U\,X = W\,V,$$

where k is the constant reduction factor appropriate to the units employed.

In the case of an elastic fluid, like air or steam, the specific volume varies with the pressure, and it is necessary to know the relation between P and V in order to solve the problem. According to the principles of hydrodynamics, the kinetic energy or "dynamic head" $\frac{U^2}{2g}$ in the case of an elastic fluid is equal to the integral of

* Proceedings, Royal Society, 1900, Vol. lxvii, p. 266.

VdP * from P_o to P, where P_o is the pressure when $U = O$. In the earliest attempts to solve the problem on these principles, it was naturally assumed that V varied inversely as P according to Boyle's law, as Newton had supposed in calculating the velocity of sound. The formula for the discharge of air through an orifice from a pressure P_o to a pressure P, calculated by Navier on this assumption, led to the result that the discharge should increase to a maximum when $P = 0{\cdot}60\ P_o$, but should diminish to zero as the back-pressure P was reduced to O, supposing that the actual pressure at the orifice remained always equal to the back-pressure. The improbability of such a consequence was remarked by Coriolis in discussing some experiments of de Pambour, and led to further experiments undertaken by de St. Venant and Wantzel.†

These observers appear to have been the first to calculate the discharge by means of the *adiabatic* relation $PV^m =$ constant, of Laplace and Poisson, in place of Boyle's law. They expressed the discharge, as was then customary, in terms of the "reduced velocity,"

$$U_r = \frac{UV_o}{V},$$

where

$$\frac{V_o}{V} = \left(\frac{P}{P_o}\right)^{\frac{1}{m}}.$$

When expressed in our notation their formula becomes :—

$$\frac{W}{X} = \frac{kU}{V} = \frac{kU_r}{V_o} = \left(\frac{k}{V_o}\right)\left(\frac{P}{P_o}\right)^{\frac{1}{m}}\sqrt{\frac{2gmP_oV_o}{m-1}\left(1-\left(\frac{P}{P_o}\right)^{1-\frac{1}{m}}\right)}$$

which is undoubtedly correct according to the assumptions made in the proof, and is still, in fact, commonly employed, with different values of the index m and the numerical constant k, for calculating the discharge of elastic fluids through orifices.

* This formula is commonly attributed to de St. Venant, or to Weisbach or Zeuner, but is nearly, if not quite, as old as Newton, who employed equivalent methods.

† *Comptes Rendus*, 1839. This formula is given in most text-books on the Steam-Engine. For deduction, *see*, for instance, Ewing, *Steam-Engine*, p. 213.

The experiments of de St. Venant and Wantzel on the flow of air through small orifices, though made on a small scale, have in the main been confirmed by subsequent work. They found that the flow through a convergent orifice, having a smooth curve of entry, agreed fairly with their formula up to the point of maximum flow, after which the flow remained constant, being independent of the back-pressure when this was further reduced. They inferred that the pressure at the orifice ceased to be equal to the back-pressure, and remained constant after the maximum point was reached. For an orifice in a thin plate, or for a divergent orifice having an abrupt entry, they found the discharge much smaller than for a convergent orifice under similar conditions. This implied the existence of a *vena contracta*, or contraction in the jet, as would naturally be expected from the analogous case of a liquid jet. The coefficient of contraction, instead of remaining nearly constant, as in the case of a liquid, increased from 0·60 when the pressure difference was small, to 0·90 for the maximum discharge. They also noticed that in the case of a convergent-divergent orifice, having smooth curves both of entry and exit, the discharge was *greater* than that given by the formula when the back-pressure exceeded the value for the maximum, and they inferred that in this case the pressure in the throat of the orifice must be *less* than the back-pressure. These remarkable results, though somewhat roughly observed, have been confirmed by recent work in almost every particular both for air and steam.

Thermodynamical Solution.—The defect of the purely dynamical solution is that it gives only the limit in frictionless flow, for an ideal substance obeying the type of equation assumed, and affords no clue as to the effect of friction or of the departure of the fluid from the laws of a perfect gas. The thermodynamical solution became possible at a later date, when the laws of thermodynamics had been established, and appears first to have been given by Joule and Thomson,* in connexion with their famous experiment of the "porous plug" or throttle.

* Proceedings, Royal Society, 1856, Vol. viii, p. 178.

If the total heat H is defined as the thermodynamic function $E + aPV$, it follows directly from the conservation of energy that the velocity U in steady flow along a pipe of variable section, if there is no external loss of heat or energy, is given by the relation:

$$\frac{U^2}{2Jg} = H_0 - H,$$

where J is the mechanical equivalent, g the acceleration of gravity, and H_0 the value of H when $U = 0$.

It is easily seen that this solution agrees with the purely dynamical solution in the case of frictionless stream-line flow, since the general expression for dH is $Td\phi + VdP$, which reduces to VdP, when $d\phi = 0$, for reversible flow at constant entropy ϕ. The drop of total heat $H_0 - H$ is, in this case, equal to the integral of VdP from P_0 to P. When there is no friction, the flow is reversible, and U, P, and V will have the same values at all points where the cross-section X is the same. In practice there is always some friction, but the thermodynamical relation $\frac{U^2}{2Jg} = H_0 - H$ still holds (if there is no external heat loss), however great the friction, and the value of H will still be the same at all points where U is the same. The entropy, however, is no longer constant, and for any given value of X at different points of the pipe, P will diminish and V will increase as we proceed along the pipe in the direction of the flow.

The thermodynamical solution gives the velocity at any point in terms of the heat-drop, which may be determined by independent experiments; but it also provides indirectly a means of determining the variations of H, by observing the pressure and temperature at points where U and H are the same, which was, in fact, the primary object of Joule and Thomson's experiments. They were unable at the time, from want of experimental data, to apply their solution except in the case of a perfect gas, for which $H_0 - H = S(T_0 - T)$, where S is the specific heat at constant pressure, assumed constant and equal to $\frac{mR}{(m-1)}$. R is the constant in the equation $PV = RT$, and m the index in the adiabatic equation

PV^m = constant. They gave the expression for the velocity of efflux at the orifice in the form,

$$\frac{U^2}{2g} = J(H_o - H) = \frac{mP_oV_o}{m-1}\left(1 - \frac{T}{T_o}\right),$$

which is seen to be equivalent to that of de St. Venant and Wantzel since $\frac{T}{T_o} = \left(\frac{P}{P_o}\right)^{1-\frac{1}{m}}$. They also expressed the discharge in terms of the "reduced velocity" $U_r = \frac{UV_o}{V}$, and showed that the maximum value of the ratio of the reduced velocity to the velocity of sound in the gas *at the original temperature* T_o could not exceed a certain value, 0·578 in the case of air, which corresponds to the ratio $\frac{P}{P_o} = 0{\cdot}527$, giving the maximum discharge for air according to the formula of de St. Venant and Wantzel. But they do not appear to have noticed a much simpler relation between the velocity of efflux and that of sound, which also follows from the same formula, or to have explained why the flow after reaching the maximum should remain constant when the back-pressure was further reduced.

Interpretation of the Formula by Osborne Reynolds.—The expression for the discharge given by de St. Venant and Wantzel has a maximum when the ratio of the pressure P at the orifice to the initial pressure P_o is given by the relation,

$$\frac{PV}{P_oV_o} = \left(\frac{P}{P_o}\right)^{1-\frac{1}{m}} = \frac{2}{(m+1)},$$

in which case the expression for the velocity of efflux U at the orifice reduces to the form

$$U^2 = mgPV,$$

which is the well-known equation for the velocity of sound in the fluid in the state (P, V) in which it exists at the orifice. This simple result seems first to have been noticed by Osborne Reynolds,*

* *Phil. Mag.*, March 1886.

who explained the experimental fact that the discharge became independent of the back-pressure when the ratio of the back-pressure to the initial pressure was less than the value corresponding to the maximum discharge, by observing that no variation in the back-pressure could reach the orifice in this case, since a variation of pressure could not be propagated through the fluid with a velocity greater than that of sound. He also showed that the equation for the discharge should be interpreted as giving the variation of the cross-section of the stream with pressure in frictionless steam-line flow. The cross-section of a given stream W has a minimum when the velocity reaches that of sound, after which the stream expands with increasing velocity as the pressure diminishes. Interpreted in this way, as representing the variation of X, the equation of de St. Venant and Wantzel is no longer meaningless when the ratio $\frac{P}{P_0}$ is less than the critical value corresponding to the maximum of $\frac{W}{X}$.

This idea has since received an important practical application in the design of the expanding nozzle invented by de Laval for obtaining the maximum velocity for a given drop of pressure. Assuming that the behaviour of the fluid can be represented by an equation of the type $PV^m =$ constant in adiabatic flow, the cross-section of the nozzle at the delivery end may be determined for a given flow by substituting the required value of the ratio $\frac{P}{P_0}$ of the final to the initial pressure in the equation of de St. Venant and Wantzel. The cross-section at the throat may similarly be determined from the value of the ratio $\left(\frac{P}{P_0}\right)^{1-\frac{1}{m}} = \frac{2}{(m+1)}$, corresponding to the minimum cross-section. The cross-section at each point determines the pressure and volume, provided that the contour is sufficiently smooth to secure stream-line flow, and that the pressure at the exit is equal to the back-pressure.

Application to the Discharge of Steam.—In applying the equation of de St. Venant and Wantzel to calculate the maximum discharge

of steam through a nozzle for a given throat area X, the simplest method of procedure is to assume an equation of the type $PV^m =$ constant to represent the adiabatic flow, with an appropriate value of the index. In the case of steam initially dry and saturated, it has been usual to take the value $m = 1\cdot135$ given by Zeuner, deduced from Regnault's formulæ for H and h with values of V calculated from $H - h$ and $\frac{dp}{dt}$ to satisfy Clapeyron's equation. The value $m = 1\cdot135$ gives immediately for the ratio of the throat pressure P_t to the initial pressure,

$$\frac{P_t}{P_o} = \left(\frac{2}{2\cdot135}\right)^{\frac{1\cdot135}{0\cdot135}} = 0\cdot5770,$$

which gives for the maximum discharge

$$\frac{W}{X_t} = k(0\cdot577)^{\frac{1}{m}}\left(\frac{2gmP_o}{(m+1)V_o}\right)^{\frac{1}{2}}.$$

From which we deduce the numerical formulæ:

$$\frac{W\text{ (lb. per sec.)}}{X\text{ (sq. in.)}} = 0\cdot3003\sqrt{\frac{P_o\text{ (lb. per sq. in.)}}{V_o\text{ (cu. ft. per lb.)}}},$$

$$\frac{W\text{ (kg. per sec.)}}{X\text{ (sq. cm.)}} = 0\cdot01990\sqrt{\frac{P_o\text{ (kg. per sq. cm.)}}{V_o\text{ (cu. m. per kg.)}}}$$

in the systems of units most commonly employed.

It is generally most convenient to take the required value of V_o from the tables, and extract the square root of $\frac{P_o}{V_o}$ with a slide-rule. But the formulæ may also be expressed in terms of P_o alone, by substituting from the empirical relation for saturated steam $P_oV_o^{\frac{16}{15}} = 490$ for English units, or $1\cdot786$ for metric units, as above defined. We thus obtain the formulæ,

$$\frac{W}{X}\text{ (lb. per sec. sq. in.)} = 0\cdot01646\ P_o^{\frac{31}{32}}\text{ (lb. per sq. in.)},$$

$$\frac{W}{X}\text{ (kg. per sec. sq. cm.)} = 0\cdot01516\ P_o^{\frac{31}{32}}\text{ (kg. per sq. cm.)},$$

which are sometimes more convenient, but require the use of logarithms in their application. The formula in this shape appears

first to have been given by Grashof,* deduced in the same way, but with slightly different values of the constants. It gives results sufficiently close for many purposes, but is not quite satisfactory from a theoretical standpoint, because the index 1·135 in Zeuner's formula is variable, and it is hardly fair to apply the equations of a perfect gas to a vapour like steam, when the specific heat and the volume are known to deviate 20 per cent. or more from the ideal values within the experimental range.

Effect of Supersaturation.—In addition to the above objections to the formulæ commonly employed, there is a physical objection of much greater weight—namely, that steam cannot condense reversibly in the time taken to reach the throat of the nozzle, and that the adiabatic equation for wet steam does not, therefore, apply to the maximum discharge determined by the state in the throat. It is well known that dry steam, when cooled by rapid expansion beyond the saturation point, does not condense unless suitable surfaces or nuclei are present to start the condensation. It is also a familiar observation that steam issuing from a jet does not appear cloudy for an appreciable space beyond the throat. It is, in fact, physically impossible that any material condensation should occur in the time occupied in reaching the throat of the jet, which is generally of the order of 0·0001 second.

It follows that the adiabatic equation which applies to the discharge is not that of wet steam, but that of dry superheated or supersaturated steam. According to the author's equations, the appropriate value of the index m is 1·30, which makes a considerable difference, and agrees much better with observations of the discharge than the value 1·135 for wet steam commonly employed. It is a fortunate circumstance that the adiabatic equation for supersaturated steam is the same as that of a perfect gas, in spite of the relatively large deviations of the vapour from the ideal state. But it would not be justifiable to use this equation if it had not been shown by theory and experiment that it was thermodynamically consistent

* Theor. Masch. Leipzig, 1875.

(1) with the characteristic equation, (2) with the cooling effect in expansion through a throttle, (3) with the variation of the specific heat, and also (4) with the equation of saturation pressure. The correspondence of the author's formulæ in all these cases is thermodynamically exact. It is important to observe that the adiabatic equation for supersaturated steam represents a maximum limit of discharge. If any condensation occurs, as is theoretically possible to a slight extent if the steam is initially wet, this will tend to *reduce* the discharge by liberating heat and raising the temperature. But the expansion ratio from the initial state to the throat is only 1·6, and the condensation at the throat must be very small. On the other hand, for large ratios of expansion the condensation must be extremely rapid *after passing* the throat, and the steam in the final state may generally be treated as wet without serious error.

Equations for Discharge of Superheated or Supersaturated Steam.—According to the author's equations, the relation between P and V in the adiabatic expansion of dry steam, whether superheated or supersaturated, is

$$P^n(V - b)^{n+1} = \text{constant, or } P(V - b)^m = \text{constant,}$$

where $$m = 1 + \frac{1}{n} = 1 \cdot 30.$$

The small constant b is the volume of the liquid at low temperatures, namely, 0·0160 cubic feet per lb., or 0·001 cubic metre per kilogram.

The corresponding expression for the total heat, $H = E + aPV$, is,
$$H = a(n + 1)P(V - b) + abP + B,$$
where B is a constant having the value 464·0 calories on the Centigrade system, or 835·2 B.Th.U. on the Fahrenheit system, and a is the numerical factor reducing PV to heat units.

These equations may be combined with the equation of flow $kUX = WV$, and the thermodynamical relation $\frac{U^2}{2g} = J(H_o - H)$, to determine the maximum discharge in adiabatic flow, in the following manner.

The condition that the flow W is to be a maximum for a given value of the throat section X, or that X is to be a minimum for a given valve of W, gives immediately the simple relation,

$$\frac{dU}{dV} = \frac{U}{V}.$$

Eliminating $\frac{dU}{dV}$ by differentiating the equation $\frac{U^2}{2g} = J(H_o - H)$, we find,

$$-\frac{U^2}{JgV} = \frac{dH}{dV} = a(n+1)P + a(n+1)(V-b)\left(\frac{dP}{dV}\right) + ab\left(\frac{dP}{dV}\right).$$

Substituting the value of $\frac{dP}{dV} = \frac{-mP}{V-b}$ from the adiabatic equation, we obtain

$$\frac{U^2}{V^2} = \frac{amJgP}{V-b},$$

which is the exact expression for the velocity of sound in the vapour in the state (P,V), and differs from the expression usually given only by the small quantity b, which is commonly neglected. This term is theoretically required, even in the case of hydrogen, the most perfect of all known gases, in order to explain the Joule-Thomson heating-effect, which is of great practical importance in the liquefaction of hydrogen. It is also required to explain the limit of compressibility of gases, and the increase of the velocity of sound for intense disturbances. Since, however, b is very small, and its exact value necessarily uncertain, the equation may be reduced to the simpler form,

$$\frac{U^2}{Jg} = amP(V+b),$$

which gives the throat velocity in terms of P and V in the throat.

State of the Fluid in the Throat.—In order to find the state of the fluid in the throat in terms of the initial state P_oV_o, we may substitute this expression for the velocity in the equation $\frac{U^2}{Jg} = 2(H_o - H)$, thus,

$$amP(V+b) = 2a(n+1)\left[P_o(V_o - b) - P(V-b)\right] + 2ab(P_o - P),$$

which gives on reduction, since $m = \frac{(n+1)}{n}$,

$$(2n+1)\left[P(V-b) + \frac{2bP}{n+1}\right] = 2n\left[P_o(V_o - b) + \frac{bP_o}{n+1}\right].$$

Eliminating either P and P_o, or V and V_o, by the aid of the adiabatic equation $P(V-b)^m = P_o(V_o-b)^m$, we obtain, since $\frac{(2n+1)}{2n} = \frac{23}{20}$,

$$\frac{P}{P_o} = \left(\frac{20}{23}\right)^{\frac{13}{3}} - 0\cdot139\frac{b}{V_o} = 0\cdot5457 - 0\cdot139\frac{b}{V_o}$$

$$\frac{V}{V_o} = \left(\frac{23}{20}\right)^{\frac{10}{3}} - 0\cdot280\frac{b}{V_o} = 1\cdot5934 - 0\cdot280\frac{b}{V_o},$$

in which the small terms depending on b have been calculated to the same order of accuracy as in the equation $\frac{U^2}{Jg} = amP(V+b)$, in order to show their relative importance. Since these terms only amount to 0·3 per cent. on the change of pressure, and 0·5 per cent. on the change of volume, respectively, for saturated steam at a pressure of 300 lb. per square inch, they may be neglected for most practical purposes.

The following expressions for the heat-drop between the initial state and the throat may also be obtained very easily,

$$H_o - H = \tfrac{3}{23}(H_o - B) + 0\cdot55\,abP_o =$$
$$0\cdot13042\,(H_o - B)\left(1 + 0\cdot97\frac{b}{V_o}\right).$$

The correction depending on b amounts to 1 per cent at 300 lb. per square inch.

The expression for the discharge $\frac{W}{X_t}$ per unit area of throat is found by substituting the values of U and V in the equation $\frac{W}{X_t} = \frac{kU}{V}$, giving

$$\frac{W}{X_t} = k\frac{U}{V} = k\sqrt{\frac{amJgP}{V-b}}$$

in terms of P and V, which becomes, in terms of P_o and V_o,

$$\frac{W}{X_t} = 0\cdot5852\,k\left(amJg\frac{P_o}{V_o}\right)^{\frac{1}{2}}\left(1 + 0\cdot274\frac{b}{V_o}\right),$$

which gives for the discharge in lb. per second per square

inch of throat, when the pressure is in lb. per square inch, and the volume in cubic feet per lb.,

$$\frac{W}{X_t} = 0\cdot3155\left(1 + 0\cdot274\,\frac{b}{V_o}\right)\left(\frac{P_o}{V_o}\right)^{\frac{1}{2}} \text{ (for any state).}$$

Neglecting the small correction, which is 0·27 per cent. at $P_o = 300$ lb., and substituting for V_o from the empirical equation for dry saturated steam, namely, $pV^{\frac{16}{15}} = 490$, we obtain *for steam initially dry and saturated*,

$$\frac{W}{X_t} = 0\cdot01730\, P_o^{\frac{31}{32}}, \text{ in terms of the same units.}$$

The corresponding formulæ in metric units giving the discharge in kilograms per second per cm^2, when P is in kilograms per cm^2, and V in m^3 per kilogram, are

$$\frac{W}{X_t} = 0\cdot02090\left(1 + 0\cdot274\,\frac{b}{V_o}\right)\left(\frac{P_o}{V_o}\right)^{\frac{1}{2}} \text{ (for any state)}$$

$$\frac{W}{X_t} = 0\cdot01593\, P_o^{\frac{31}{32}} \text{ (for saturated steam)}$$

which may be compared with those already given for the index $m = 1\cdot135$.

Comparison of Expressions for Discharge with Experiment.—It will be observed on comparing these expressions for the discharge of supersaturated steam with those previously given according to the generally accepted theory, that the limit of discharge for supersaturated steam with $m = 1\cdot30$ is very nearly 5 per cent. greater than for wet steam with $m = 1\cdot135$, and that the ratio of the throat pressure to the initial pressure is about 5 per cent. lower, being 0·5457 in place of 0·5770. It is a familiar fact that most of the experiments on the discharge of steam from convergent nozzles, such as those of Minary and Resal,* Parenty,† Rosenhain,‡

* *Ann. des Mines*, ix. 1861.

† *Ann. Chim. Phys.* 1896.

‡ Proceedings Inst. C.E. 1900, Vol. cxl, p. 199.

Rateau,* have given results from 2 to 4 per cent. *higher* than the theoretical formula for wet steam. This ought to be *impossible*, apart from experimental errors, if the formula is correct, because the actual discharge must always be less than the theoretical limit on account of friction in the nozzle and contraction of the jet. But the results of experiment agree very well with the view that the steam in the throat must be in the supersaturated condition, since the effects of friction and contraction, which can be separately estimated, should generally amount to 2 or 3 per cent.

The discrepancies from the accepted formula have generally been explained (e.g., by Rateau) on the assumption that the initial steam employed by the older observers contained a considerable percentage of water, which was included in the discharge when measured by condensation and weighing. But since the presence of water would diminish the velocity as well as the volume, the percentage of water (4 to 8 per cent.) required to explain the discrepancy is much too high to admit in any experiments conducted with reasonable care. Rateau himself deduced the discharge by observing the rise of temperature of a measured stream of condensing water, in which case any error due to initial moisture in the steam would act in the opposite direction, and would make the discharge appear too small. In spite of this, his results were too high according to the theoretical formula, and he was unable to reduce them to the desired limit, although he considered and applied most carefully all possible corrections tending to reduce the discharge, but omitted to mention at least one very important correction acting the other way. In any case it would not suffice to reduce the observed values to equality with the theoretical limit, because the actual discharge must always be appreciably *less* than the limit.

There seems to be a general impression that the effect of condensation in the throat, which for wet steam in the equilibrium

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* Flow of Steam, 1905.

state should amount to about 3·4 per cent. when $\frac{P}{P_o} = 0{\cdot}58$, would be to *increase* the amount of the discharge as compared with that which would be observed if there were no condensation. As Rateau puts it, "if any retardation in the condensation occurred, experiment would reveal a deficit amounting to 3·0 to 3·5* per cent. in the quantity of steam discharged. But in place of a deficit, a too high value is always found, so that it may be concluded that if there is any retardation of the condensation it is very small, of the order of 0·00001 second."

As a matter of fact the effect of condensation is exactly the opposite, namely, to diminish the discharge by increasing the temperature and the volume; so that the theoretical limit of discharge *with condensation* is about 5 per cent. less than that without, instead of being 3 per cent. greater, as imagined by Rateau. When the initial pressure P_0 is 100 lb. abs., the drop of temperature to the throat with reversible condensation would be only 20·7° C.; but without condensation it is 57° C.; and the volume is actually *less* than with condensation, although the drop of pressure and the velocity are greater. The actual density is nearly three times the saturation density at the same temperature.

C. T. R. Wilson (Phil. Trans. 1898) has shown that, when water vapour is rapidly expanded in the absence of nuclei, condensation begins in the form of an exceedingly thick mist of very fine particles when the density is about eight times the saturation density. This appears to be the limit of the metastable state, beyond which steam cannot be expanded without condensation. Owing to the extremely rapid expansion, this kind of condensation must generally occur shortly after passing the throat, whether nuclei are originally present or not. The rate of approach to the equilibrium state of wet steam must then be extremely rapid, owing to the fineness of the mist and

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* Rateau gives 0·3 to 0·35 per cent. as the condensation when $P = 0{\cdot}58\, P_o$, but this is probably a misprint, of which there are several.

the great number of nuclei available for condensation (about 10^{22} per lb.).*

If the steam is initially wet and saturated there may be some condensation on the nuclei present before passing the throat. Callendar and Nicolson † have shown that the rate of condensation of steam per square foot per second is approximately proportional to the defect of temperature below the saturation value corresponding to the pressure. An estimate based on this law shows that the condensation which occurs during expansion to the throat must be extremely small, because all the three factors on which the condensation depends are small. The time elapsed is very short, the fall of temperature is comparatively slight, and no fresh nuclei have yet been generated. On the other hand, after passing the throat, by the time the pressure had fallen to a tenth of its initial value, the temperature would be nearly 20° C. below

* When the drops are very small, it follows from the theory of conduction of heat that the rate of condensation should depend on the number of drops rather than on the surface area of the drops. There are many known analogies to this in the case of loss of heat from fine wires, and transpiration through the pores of a leaf. Wilson (Phil. Trans. 1897, page 301) has estimated that the number of drops produced by rapid expansion of saturated air at 20° C. in the ratio 1·42 is at least 10^8 per cm^3 when the diameter of each drop is 5×10^{-5} cm., but increases with very great rapidity when the range of expansion is increased beyond this point. The number given by Wilson would correspond to about 10^{13} drops per gram of water vapour, and would be increased to about 10^{19} drops per gram if the diameter of each drop were 5×10^{-7} cm., which is more nearly of the order of magnitude required by Kelvin's equation of equilibrium of vapour pressure, when the density of the vapour is eight times the saturation density. The number of coaggregated or paired molecules in water vapour at 20° C. is about 3×10^{19} per gram of vapour, and it appears probable that these molecules are about of the right order of magnitude, namely 10^{-7} cm., to act as nuclei for condensation when the density of the vapour is eight times the saturation density. The extension of the equation of equilibrium for drops of finite size to the case of drops of molecular dimensions is somewhat speculative, but probably affords a fair idea of the order of magnitude of the numbers concerned. The result is interesting as giving an explanation of the limit beyond which steam cannot be expanded without condensation, and as indicating the actual existence of coaggregated molecules in the vapour. The number of such molecules is found to correspond in order of magnitude with that required to account for the observed deviations of the vapour from the laws of gases.

† Proc. Inst. C.E. 1898, Vol. cxxxi, p. 147. Law of Condensation of Steam.

zero if there were no condensation, and the density of the vapour would be about a thousand times the saturation density. We have no experimental knowledge of the rate of condensation under such conditions, but it is clear that it must be inconceivably rapid. It is probable that condensation begins with great rapidity shortly after passing the throat, and that in the later stages of expansion the condition of the steam approximates more and more closely to the equilibrium state of wetness, although there must always be some lag depending on the rate of expansion.

Variation of Discharge with Back-pressure.—Some additional evidence with regard to the state of the fluid in the throat may be obtained from experiments on the discharge from convergent nozzles, having a smooth curve of entry, but terminating abruptly at the throat, which projects into a space at a steady back-pressure. It is clear that, in this case, the pressure at the throat cannot fall appreciably below the back-pressure, and there should be little, if any, contraction of the jet. The ratio of the observed discharge to the maximum discharge should follow the formula of de St. Venant and Wantzel for ratios $\frac{P}{P_o}$ greater than that corresponding to the maximum discharge, since the effects of friction, or heat-loss, or other deviations from adiabatic flow, are approximately eliminated by taking the ratio of the discharge to the maximum discharge. The comparison is shown in the following Table:—

Back-pressure P in per cent. of the initial Pressure P_o.	Ratio of Discharge to Maximum Discharge.				
	For Air.		For Saturated Steam.		
	Calculated $m = 1 \cdot 400$.	Observed by Hirn.	Calculated for Values. $m = 1 \cdot 130$.	Calculated for Values. $m = 1 \cdot 300$.	Observed by Rateau.
Per cent.					
90	0·617	0·615	0·656	0·631	0·630
80	0·849	0·810	0·859	0·833	0·830
70	0·932	0·920	0·961	0·943	0·935
60	0·989	0·975	0·999	0·993	0·985

The correspondence with theory is seen to be remarkably close considering the difficult nature of the experiments. The observed values for air are all a little smaller than the calculated values. The observed values for steam show a very similar divergence from the values calculated with $m = 1 \cdot 300$, assuming the state of supersaturation in the throat, but they do not agree nearly so well with the values calculated from $m = 1 \cdot 130$ for wet steam. The discrepancy appears even more marked if the actual values of the discharge are compared with the theoretical values for wet steam. The theoretical curve in this case lies *above* the experimental curve for values of $\frac{P}{P_o}$ between $0 \cdot 90$ and $0 \cdot 70$, but crosses the experimental curve in the neighbourhood of $0 \cdot 60$, and then lies below it. Whereas if the value $m = 1 \cdot 30$ is taken for the index, the theoretical curve lies always above the experimental curve, showing a small but steadily increasing difference, which may reasonably be attributed to friction. It is hardly possible to imagine that any kind of inequality of flow in the jet could operate in such a way as to make the observed discharge too small for small pressure differences and too large when $\frac{P}{P_o}$ approaches the value corresponding to the maximum discharge; but some explanation of this kind would be required if the value of the index for wet steam were adopted as representing the limit of possible discharge.

Several experiments have also been made with orifices in thin plates, which are useful for several purposes, but do not throw much light on the theory, because the flow cannot be calculated. The results of experiment indicate a contraction in the jet approximating for small pressure differences to the value observed in the case of liquids, but the coefficient of discharge increases with fall of back-pressure, as one would naturally expect owing to the widening of the jet as the back-pressure is reduced.

The most important kind of nozzle for practical purposes is the expanding nozzle invented by De Laval for obtaining the maximum velocity for a given drop of pressure in an impulse turbine. The maximum discharge may be calculated as already

explained from the throat area with $m = 1 \cdot 30$. The sectional area corresponding to any desired pressure in the expanding portion of the nozzle may also be found by the formula of de St. Venant and Wantzel, but the state approximates to that of wet steam at low pressures, and the lower value $m = 1 \cdot 130$ of the index should be employed.

Cross-Section of Jet for Frictionless Flow.—If the expanding fluid follows the adiabatic law $PV^m =$ constant, the ratio $\frac{X}{X_t}$ of the section X of the jet at any pressure P to the throat section X_t depends only on the ratio $\frac{P}{P_o}$ of the pressure P at X to the initial pressure P_o, and is independent of the absolute value of the pressure. The following Table shows the values of this ratio calculated for selected values of the index m, for comparison with the values calculated for steam in different conditions by the aid of the Tables. The values obtained from the steam Tables depend to some extent on the initial pressure, and are calculated for an initial pressure of 100 lb. per square inch.

The calculation of $\frac{X}{W}$ from the Tables for any given value of P is made as follows. The velocity U is found from the heat-drop $H_o - H$ by the equation :—

$$\frac{U^2}{2Jg} = H_o - H = (t_o - t)\,\Phi_o - (G_o - G),$$

where H_o, t_o, Φ_o, G_o are the initial values of the total heat, temperature, entropy, and thermodynamic potential, $G = T\Phi - H$, when $U = O$. This formula gives the heat-drop in adiabatic expansion for steam in any state, whether dry or wet, superheated or supersaturated, provided that the appropriate values of G are taken from the Tables. Φ is the initial value of the entropy which remains constant. For wet steam, the temperature t is the saturation temperature corresponding to the given pressure p. For dry, or superheated, or supersaturated steam, t is found from the ratio $\frac{T}{T_o}$ which is equal to $\left(\frac{P}{P_o}\right)^{1-\frac{1}{m}}$, as in the formula of

de St. Venant and Wantzel. The heat-drop may in this case be calculated from the formula:—

$$H_o - H = a(n+1)\,P_o\,(V_o - b)\left(1 - \frac{P}{P_o}\right)^{\frac{3}{13}} + ab\,(P_o - P),$$

which is very nearly the same as that for a perfect gas. The volume, which is also required, may be found from the total heat H by the formula (Foot-Pound-Centigrade units):—

$$V = \frac{(H-B)}{a(n+1)P} + \frac{nb}{(n+1)} = 2\cdot2436\,\frac{(H-B)}{P} + 0\cdot0123.$$

In the case of wet steam, the volume V is deduced from the volume V_s and the total heat H_s for dry saturated steam at t by the relation:—

$$\frac{V_s - V}{V_s} = \frac{H_s - H}{H_s - st},$$

where H is the actual total heat, and s the specific heat of water, which may be taken as unity when the difference $V_s - V$ is small.

If approximate results only are required, the heat-drop and the volume for wet steam are most easily found from a diagram, such as Mollier's, but this method would not give sufficiently accurate results for the purpose of the present comparison, especially in the initial stages of the expansion where very small differences are involved. Thus in order to find the velocity at the throat to the nearest foot per second, it is necessary to calculate the heat-drop to two places of decimals, which is beyond the limit of accuracy to which the values are generally tabulated.

The numerical values of the constant $(2Jg)^{\frac{1}{2}}$, in the expression for the velocity in terms of the heat-drop $U = \sqrt{2Jg(H_o - H)}$, are,

H in Centigrade calories, U in ft. per sec.	$(2Jg)^{\frac{1}{2}}$	$= 300\cdot2$
H ,, ,, U in metres per sec.	,,	$= 91\cdot51$
H in B.Th.U. Fahrenheit, U in ft. per sec.	,,	$= 223\cdot8$

Having found U and V for any value of P, the corresponding value of the section per unit discharge $\frac{X}{W}$ is given by $\frac{X}{W} = \frac{V}{kU}$, where $k = \frac{1}{144}$ if X is required in sq. in. when W is in lb. per sec., U in ft. per sec., and V in cu. ft. per lb.; and $k = \frac{1}{10,000}$ for X in sq. cm., W in kg. per sec., U in m. per sec., and V in cu. m. per kg. The ratio $\frac{X}{X_t}$ given in the table is independent of the units adopted.

Ratio $\frac{X}{X_t}$ *in terms of* $\frac{P}{P_o}$ *for various cases.*

$\frac{P}{P_o}$ Per Cent.	For Perfect Gas with index.			For Steam with $P_o = 100$ lb.		
	$m = 1\cdot40$	$m = 1\cdot30$	$m = 1\cdot1304$	From Tables.	Super-saturated.	With Friction.
90	1·620	1·586	1·523	1·530	1·588	1·565
80	1·221	1·201	1·165	1·172	1·202	1·189
70	1·073	1·061	1·041	1·042	1·062	1·053
60	1·012	1·007	1·001	1·002	1·007	1·004
50	1·002	1·005	1·015	1·014	1·005	1·008
40	1·038	1·051	1·083	1·080	1·051	1·062
30	1·134	1·162	1·228	1·224	1·320	1·337
20	1·346	1·403	1·538	1·533.	1·642	1·684
10	1·931	2·075	2·420	2·418	2·576	2·699
5	2·900	3·214	3·992	4·009	4·255	4·564
2	5·159	5·959	8·052	8·158	8·660	9·580
1	8·116	9·680	13·957	14·338	15·175	17·210
X_t in sq. in. for W = 1 lb. per sec.				0·700	0·668	0·679

The values given in the column headed $m = 1\cdot40$ would represent the case of a nozzle for expanding compressed air. In the absence of friction or pre-heating, the temperature would fall below the liquefying point of air, when the pressure was reduced to 1 per cent. of its initial value. The values in the column $m = 1\cdot30$ similarly represent the case of steam when sufficiently superheated to prevent condensation. The value of the index $m = 1\cdot1304$ represents very closely the case of steam initially dry and saturated at a pressure of 100 lb. per square inch abs., on the assumption that the condensation is able to keep pace exactly with the expansion, so that the temperature of the steam is always that

of saturation corresponding with the pressure. The values calculated from the Tables for steam in this initial state are given in the next column, and show a very close agreement from 100 to 10 lb. pressure, because the value of the index 1·1304 was selected to fit this case. For lower pressures the actual expansion of the steam is rather larger than that given by the index 1·1304.

The values in the column headed "Supersaturated" are calculated on the assumption that there is no appreciable condensation until the steam has passed the throat and reached the limit of the metastable state. The steam is supposed to remain dry and supersaturated, following very closely the values given by the index 1·30, until the pressure has fallen to 35 lb. The total heat at this point is 619·2 Centigrade calories, and the volume 9·962 cubic feet per lb. At this pressure we suppose, in order to simplify the calculation, that the steam is instantaneously transformed at constant total heat into wet steam at saturation temperature $t = 126 \cdot 25^\circ$ C. This involves an increase of entropy from 1·6082 to 1·6142, and an increase of volume from 9·962 to 11·210 cubic feet per lb. In point of fact the change would be continuous, and some supersaturation would still persist at lower pressures owing to the rapid expansion. But the assumption of instantaneous transformation shows the general nature of the effect produced. Owing to the increase of entropy and diminution of heat-drop, the volume is greater and the velocity less than for wet steam at constant entropy, and a larger cross-section is accordingly required at lower pressures than is allowed on the usual method of calculation. But since the time of expansion from the throat to the end of the nozzle would be of the order of one two-thousandth part of a second, the temperature would never quite reach that of saturation, and the volume would always be less than the calculated value.

Effect of Friction in an Expanding Nozzle.—The effect of friction must always be to increase the entropy and diminish the available heat-drop for any given limit of pressure. This involves a diminution of velocity and an increase of volume as compared with the limiting values calculated on the assumption of frictionless

flow. A further increase in the section of the nozzle for a given final pressure is accordingly required in order to allow for the effect of friction, in addition to that already indicated on account of supersaturation. The two effects taken together may amount to 20 per cent. for a single nozzle with a large ratio of expansion. This is quite in accordance with the common observation that such a nozzle, designed in the usual way for a given pressure ratio, works better when the back-pressure is too high than when it is too low.

The percentage loss due to friction in a nozzle of the type considered must depend to some extent on the size and shape of the nozzle, and also on the initial and final pressures. The loss cannot be calculated with certainty, but some idea of the general effect may be obtained on fairly simple assumptions. Assuming that the frictional loss at any point varies as the square of the velocity, or directly as the heat-drop, the total *percentage* loss of heat-drop up to the point considered is approximately proportional to the heat-drop itself. This is the simplest assumption that can be made, and appears to accord fairly with most of the available data. The theoretical heat-drop at each pressure is accordingly reduced by a fraction proportional to itself, and the corresponding velocity and volume calculated for the reduced heat-drop in the usual way. Taking the *percentage* loss as one-tenth of the theoretical heat-drop in calories, we obtain the figures given in the last column of the Table as including friction. The loss of heat-drop amounts in this case to 2·6 per cent. at the throat, 9 per cent. at 10 lb., and to 16 per cent. at the limit of 1 lb.—values which are quite within the range of probability for a small nozzle with so large a range of expansion, and which require a notable increase in the sectional area of the nozzle for a given pressure.

When the heat-drop is divided into a large number of stages, as in most turbines, and the variation of velocity is small, the correction for friction and leakage may fairly be applied as a *constant* fraction (generally about $\frac{1}{3}$rd) of the heat-drop in each stage, as is usually done.

Attempts have often been made to deduce the value of the throat-pressure corresponding to the maximum discharge by

observing the pressure at which the discharge begins to fall off rapidly when the back-pressure is raised. But except in the case of the convergent nozzle terminating abruptly at the throat, there is no necessary relation between the throat-pressure and the back-pressure. The pressure at which the discharge *begins* to fall off could not be determined satisfactorily in any case, because the variation is very slow near the maximum, and it is not possible to get observations *on both sides* of the maximum. Such observations cannot give any information with regard to the throat-pressure in the case of a convergent-divergent nozzle, for which, apart from friction, the throat-pressure would be quite independent of the back-pressure, which might theoretically, in the absence of friction, be raised to equality with the initial pressure without altering the discharge. In practice, the flow is limited by friction, and begins to fall off somewhat abruptly, before the back-pressure reaches the initial pressure, when the loss due to friction in and near the throat is of the same order of magnitude as the available heat-drop, due to the pressure difference.

The principal use of such observations is to afford a means of estimating the friction, which is readily deduced from the relation,

$$U^2 - U_o^2 = 2Jg(H - H) - Q,$$

provided that due allowance is made for any heat-loss Q, and that the final temperature is observed as well as the pressure, so that the final values U and H can be estimated. The loss due to friction is then approximately represented by the defect of the actual heat-drop $H_o - H$ from the drop due to the pressure difference in adiabatic expansion. The friction estimated in this way for a given discharge is found to increase with the final volume and velocity in the manner already indicated, but none of the observations hitherto recorded can be accurately reduced owing to the uncertainty of the heat-loss, and the omission to record the final temperatures. It has therefore been considered undesirable to discuss them in detail, or make any attempt to tabulate the values. The results so far as they go are in good agreement with

the view that the steam is supersaturated in the throat, but cannot easily be reconciled with the generally accepted formulæ.

Summary.—The primary effect of supersaturation in the throat of a nozzle is to increase the discharge by about 5 per cent. as compared with that calculated on the usual theory with a given throat area. The secondary effect is to cause an increase of entropy and volume when the steam becomes wet after passing the throat. The two effects require, for a given throat area and ratio of initial to final pressure, an increase of 6 to 8 per cent. in the final area of the cone, or an increase of length of 3 to 4 per cent. in the diverging cone for a given angle of divergence.

The effect of friction in the throat is to reduce the discharge by a small fraction, which appears to vary inversely as the initial pressure, and inversely as the throat diameter for similar nozzles. The order of magnitude of this fractional reduction, for a well-designed nozzle with smooth contours, appears to be given by the formula $\frac{1}{P_0 D}$, where P_0 is the initial pressure in pounds per square inch abs., and D the diameter of the throat in inches.

The effect of friction beyond the throat increases with increase of velocity and diminution of final pressure, and may be estimated with some degree of probability by taking the percentage loss of heat-drop to be proportional to the heat-drop itself. The diminution of velocity and increase of volume due to friction may require an increase of 10 to 20 per cent. in the final area, equivalent to an increase of length of 5 to 10 per cent. for a given angle of divergence, as compared with the length calculated for the case of frictionless flow. Increasing the length of a nozzle, for a given final section and pressure, by reducing the angle of divergence, increases the loss due to friction, but reduces the loss due to residual supersaturation by allowing more time for the steam to condense, and also gives a more nearly parallel and effective stream. The angle of divergence giving the best results in practice is probably such as to balance these opposite effects.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1915.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 22nd January 1915, at Eight o'clock p.m.; MICHAEL LONGRIDGE, Esq., Vice-President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The CHAIRMAN announced that, in accordance with Article 23, the President, two Vice-Presidents, and seven Members of Council would retire at the ensuing Annual General Meeting; and the complete list of those retiring was as follows:—

PRESIDENT.

Sir H. FREDERICK DONALDSON, K.C.B., . . . Woolwich.

VICE-PRESIDENTS.

Sir J. WOLFE BARRY, K.C.B., LL.D., F.R.S., . . London.
W. CAWTHORNE UNWIN, LL.D., F.R.S., . . . London.

MEMBERS OF COUNCIL.

WILLIAM H. ALLEN, ... Bedford.
GEORGE J. CHURCHWARD, ... Swindon.

J. ROSSITER HOYLE, ...	Sheffield.
HENRY A. IVATT, ...	Hayward's Heath.
Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S., ...	London.
*WILLIAM H. PATCHELL, ...	London.
The Right Hon. Lord PIRRIE, K.P., P.C., LL.D., ...	London.

Of the foregoing, the following were hereby nominated by the Council for election, with their consent:—

For PRESIDENT.

W. CAWTHORNE UNWIN, LL.D., F.R.S., .	London.

For VICE-PRESIDENTS.

WILLIAM H. ALLEN, ...	Bedford.
J. ROSSITER HOYLE, ...	Sheffield.

For MEMBERS OF COUNCIL.

Sir J. WOLFE BARRY, K.C.B., LL.D., F.R.S.,	London.
HENRY A. IVATT, ...	Hayward's Heath.
Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S., ...	London.
WILLIAM H. PATCHELL, ...	London.

The following Nominations were also made by the Council for election at the Annual General Meeting, and have consented:—

For MEMBERS OF COUNCIL.

Election as Member.		
1899.	JOHN DEWRANCE, ...	London.
1891.	Sir J. ALFRED EWING, K.C.B., LL.D., F.R.S., ...	Edenbridge.
1895.	CHRISTOPHER W. JAMES, . . .	Leeds.
1893.	VINCENT L. RAVEN, ...	Darlington.
1907.	WILLIAM REAVELL, ...	Ipswich.
1876.	JAMES W. RESTLER, ...	London.

* Appointed during the year.

The CHAIRMAN reminded the Meeting that, according to By-law 26, any Member or Associate Member was then entitled to add to the list of candidates.

No other names being added, the CHAIRMAN announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The CHAIRMAN announced that the Ballot Lists for the election of new Members had been opened by a Committee appointed by the Council, and that the following fifteen candidates were found to be duly elected :—

MEMBERS.

CALDER, WILLIAM,	Johannesburg.
STOKES, ISAAC WESTLEY,	Bombay.

ASSOCIATE MEMBERS.

BARR, GEORGE,	London.
BARWICK, HORACE JOHN,	Abeokuta.
BRITTON, FRANK GUYVER,	Yokohama.
CLUTTERBUCK, HERBERT CHARLES,	Portsmouth.
FOTHERGILL, HARRY,	London.
GRAHAM, JACK CURTIS,	London.
HAMPTON, JAMES,	Southampton.
HODSON, WILLIAM JAMES,	Cachar, India.
SMITH, CHARLES ALFRED,	London.
WELLS, WILLIAM,	Antofagasta.
WILLIAMS, PERCY,	London.

GRADUATES.

BONAR, DAVID DOUGHTY MILL,	Hull.
SANDFORD, HORATIO ADLINGTON,	Gravesend.

The CHAIRMAN announced that the following five Transferences had been made by the Council:—

Associate Members to Members.

HARTLEY, RICHARD FREDERICK, . . .	Woolwich.
HURST, JOSEPH HENRY, ...	Sheffield.
KENNEDY, CHARLES, ...	Pernambuco.
LORIMER, ALEXANDER SMITH, . . .	Glasgow.
PAYNE, RAYMOND, ...	London.

The following Paper was read and discussed:—

"Standardization of Pipe Flanges and Flanged Fittings" by JOHN DEWRANCE, *Member*, of London.

The Meeting terminated shortly after Half-past Nine o'clock. The attendance was 50 Members and 10 Visitors.

STANDARDIZATION OF PIPE FLANGES AND FLANGED FITTINGS.

BY JOHN DEWRANCE, *Member*, OF LONDON.

The standardization of pipe flanges and of flanged fittings is a matter of great importance to both manufacturers and users, and it has during recent years received much attention in this and other countries. On 18th April 1902, Mr. Robert E. Atkinson (*Member*), of Leicester, read before this Institution a Paper in which he dealt in a most thorough and painstaking way with the position of the subject at that date. Largely as a result of Mr. Atkinson's Paper, and of the valuable discussion to which it gave rise, the matter was, in the following year, taken up by the Engineering Standards Committee, who appointed a Sectional Committee on Pipe Flanges to deal with the question. This Committee, at that date, included representatives of the Admiralty, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the North East Coast Institution of Engineers and Shipbuilders, the Institution of Engineers and Shipbuilders in Scotland, the Institute of Marine Engineers, the Institution of Heating and Ventilating Engineers, the Association of Railway Locomotive Engineers, and the British Tube Trade Association, besides representatives of many important manufacturing firms engaged in the construction of pipes, valves, etc. This Committee held its first meeting on 30th June 1903, and from it there was formed a smaller sub-committee, entrusted with the task of studying details and carrying out any experiments which might be necessary.

The sectional committee and sub-committee held in all thirty meetings, at which they received and discussed a great mass of information relating to existing practice, and also the data derived from various experiments carried out in the course of the inquiry. As a result, they embodied their conclusions in a Report* in which the flanges, etc., are standardized in four classes, viz.:— (1) low-pressure standard, for steam pressures up to 55 lb. and water pressures up to 200 lb. per square inch; (2) intermediate-pressure standard, for steam pressures over 55 lb. but not exceeding 125 lb. per square inch; (3) high-pressure standard, for steam pressures over 125 lb. but not exceeding 225 lb. per square inch; and (4) extra high-pressure standard, for steam pressures exceeding 225 lb. but not exceeding 325 lb. per square inch. The report also gives standard dimensions for short bends and tees of cast metal and for long bends of wrought-iron and steel.

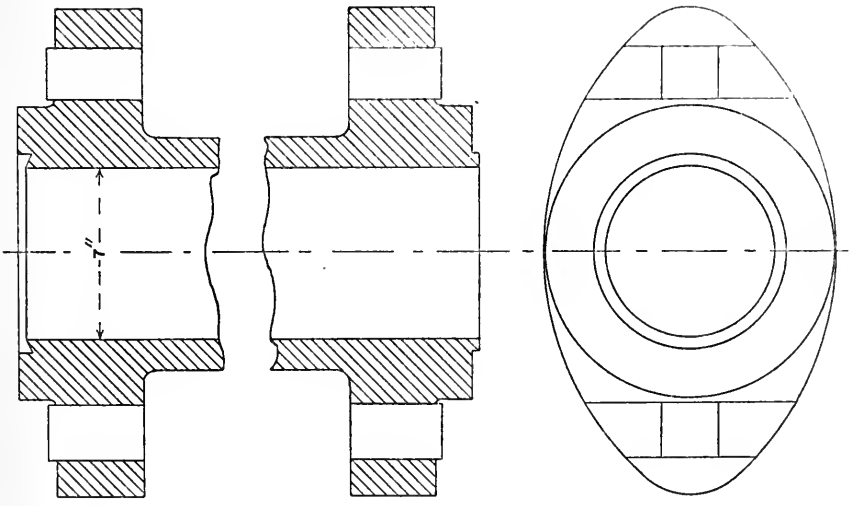
The work of the Committee necessarily demanded the careful consideration of a number of points of detail, it being especially desired to arrive at such standards as would, on the one hand, ensure efficient joints, and, on the other, avoid undue weight; while, moreover, it was necessary—in order to realize the full value of standardization—that the standards arrived at should be such as would be suitable for stocking in quantities by the makers of pipes, valves, etc. Some of these points may be considered separately.

Diameters of Flanges and Bolt-Hole Circles.—In the British Standard Tables of Pipe Flanges, the diameters of flanges and bolt-hole circles are uniform for all flanges intended for steam pressures ranging from 55 lb. to 325 lb. per square inch, slightly smaller flanges, however, being given for the low-pressure flanges forming Class 1, and intended for steam pressures up to 55 lb. per square inch. The diameters of bolt circles decided upon were the smallest permissible in the case of cast fittings, after making due allowance for the fillet at the root of the flange and without resorting to pin drilling to secure a flat bearing face for the nuts.

* British Standard Tables of Pipe Flanges, No. 10, Nov. 1904.

Number of Bolts.—One of the most important points that came before the sub-committee for decision was, whether or not the number of bolts employed should in all cases be a multiple of four, and a great deal of discussion occurred before a conclusion was arrived at. Careful consideration was given to standards in which the number of bolts increased one at a time, and others where the number increased two at a time, and the opinions of a great number of engineers were asked and considered.

FIG. 1.—*7-inch Cast-iron Pipe for Hydraulic Power.*
1,200 lb. Pressure per square inch.



Every one present will be aware that hydraulic-press cylinders and heads are often connected by two bolts, and seldom by more than four. Cast-iron pipes up to 7-inch bore for hydraulic power up to 1,200 lb. pressure per square inch are made with two bolts.* Fig. 1 shows the 7-inch size.

The reason only two bolts are used in the case of hydraulic mains is that several pipes are laid side by side in trenches in the

* *See* British Standard Specification for Cast-Iron Pipes for Hydraulic Power, No. 44.

streets, but in order to be able to run the pipes in any direction, the standard tee bends and the valves must be made in three variations—one with the flanges vertical, another with the flanges horizontal, and still a third with one flange vertical and the other horizontal. This leads up to the conclusion arrived at by the sub-committee, that there can practically be no standard at all unless the numbers of bolts used are multiples of four.

It follows from the preceding paragraph that four bolts would be sufficient for even the largest steam-pipe flanges, but, in the larger sizes, the use of four bolts only would involve setting the bolt bracket back, as is done in the hydraulic pipe flanges. This would require longer bolts, which, of course, would have to be larger to stand the strain, and would entail a greater cost than the use of the number of smaller bolts that was adopted. In this respect, as in others, the sub-committee departed as little as possible from existing practice and followed the rule that, whenever room for four more bolts occurred, they were added.

The sizes of the bolts were calculated throughout to allow an ample margin of safety, assuming that, in the case of a joint on the point of leaking, the full pressure might be exerted on the area of a circle just touching the inside of the bolt holes.

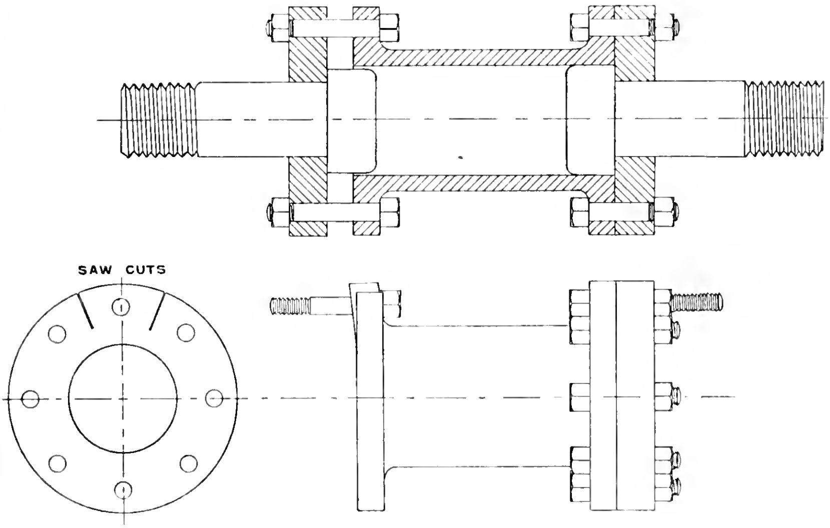
The clearance of $\frac{1}{16}$ inch in the bolt holes for $\frac{1}{2}$ inch and $\frac{5}{8}$ inch bolts, and of $\frac{1}{8}$ inch for larger sizes, was, in the opinion of the sub-committee, the smallest allowance that was practicable for commercial manufacture.

Thickness of Flanges.—A considerable amount of the time occupied by the sub-committee was given to the consideration of the thickness of flanges. Many theories as to the formulæ put forward on this subject were considered, but the sub-committee did not agree as to any formula that could be accepted for general use.

The author's view is that two separate stresses have to be considered. The first is the stress necessary to distort the flange and the pipe considered as a cantilever, and the second is the stress necessary to cup the flange itself. To demonstrate this, a short piece of $2\frac{1}{2}$-inch bronze pipe with two of the standard flanges,

$7\frac{1}{4}$ inches diameter and $\frac{11}{16}$ inch thick, was made and drilled with eight holes to the British standard. One flange was bolted up to a cast-iron flange and the other flange was connected by bolts to another thick cast-iron flange, leaving a space between the bronze and cast-iron flange, as shown by Fig. 2. The cast-iron flanges were then pulled apart in a testing machine. At 17·28 tons the last-mentioned bronze flange set $\frac{1}{32}$ inch and at 19·2 tons it set $\frac{1}{8}$ inch.

FIGS. 2 and 3.—*Tests on Bronze Flanges.*



Front view. Side view.

Two radial saw cuts were then made in the undistorted flange, as shown in Fig. 3. These cuts bisected the distances between one of the bolt holes and the holes on either side of it, and ran down the radius from the outside circumference of the flange until they met the barrel of the pipe. In this way one-eighth part of the flange was isolated from the rest.

A bolt was passed through the hole in this isolated portion and another through the corresponding hole in the complete flange, and the cantilever strength of the small portion was tested between the

centres of a testing-machine in the ordinary way, as shown in Fig. 3. A set of $\frac{1}{8}$ inch was obtained with a load of 1·27 tons.

This experiment proves that the flange owes 1·27 tons for each section of an eighth, or 10·16 tons in all, to the cantilever strength, and the balance of the 19·2 tons or 9·04 tons to the strength of the flange itself.

A flange $6\frac{1}{2}$ inches diameter for 2-inch pipe, and having four bolts, was then taken and pulled in a similar way: at 14·3 tons there was a permanent set of $\frac{1}{32}$ inch, and at 16·99 tons a permanent

FIG. 4.—*Flange with 4 Bolts.*
13 tons permanent set $\frac{1}{64}$ inch.
15·27 ,, ,, ,, $\frac{1}{8}$ inch.

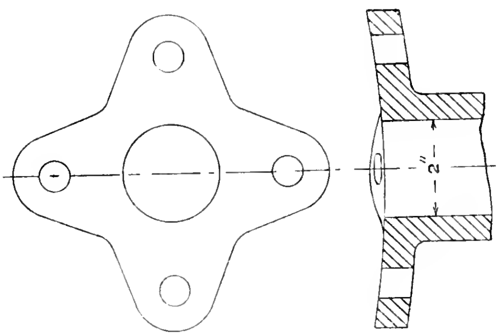
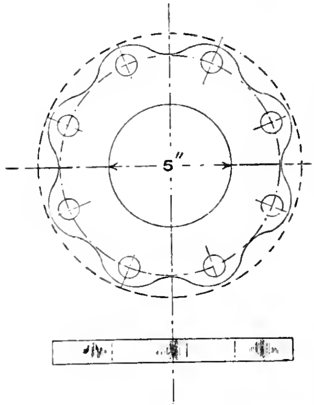


FIG. 5.—*Flange with 8 Bolts.*
5 lb. 10 oz. saved in weight.



set of $\frac{1}{8}$ inch. An exactly similar flange was then reduced to the shape shown by Fig. 4. At 13 tons there was a permanent set of $\frac{1}{64}$ inch, and at 15·27 tons a permanent set of $\frac{1}{8}$ inch.

This result was extremely interesting, as the metal between the bolts on the line of the bolt circle having been cut away, it proved that formulæ based on strength of the girder between the bolts are not correct; it also proved that there is an ample margin of strength when four bolts are used for a 2-inch flange.

The result of this experiment also suggests that, if it be very important to keep the weight down as low as possible, flanges need not be round, but might be of a shape similar to that shown by

Fig. 4, or, in the case of eight bolts, by Fig. 5. Such flanges could be bolted to round flanges to the British standard and not be very unsightly. In the 5-inch size shown by Fig. 5, 5 lb. 10 oz. would be saved in the weight of the flange.

The thicknesses of the flanges embodied in the standard Tables were arrived at by the sub-committee as the result of actual experiments conducted for them. These experimental flanges were jointed with red-lead paint and baked for 24 hours above steam heat; they were then tested till they leaked, and the thickness adopted in all cases showed a satisfactory margin of strength. The sub-committee, however, did not provide for test pressures more than 100 lb. in excess of the working pressures, and if greater test pressures of the complete pipe-lines were required, the thickness of the flanges would have to be increased. Hydraulic tests of individual units can, however, be made, with temporary elastic packings, to test the soundness of the material.

It will be understood that the stiffness of any given flange is largely dependent upon the distance between the exterior of the pipe or valve body and the bolt circle, and it follows that any reduction in the thickness of the metal of a pipe or valve casing weakens the flange. This effect is noticeable in the case of steel or wrought-iron pipes having welded-on flanges, a form of construction which is now so largely used. If the welded-on flange is provided with a boss or collar round the pipe, the conditions approximate to those of a casting; but if the flange is a plain disk, as is very generally the case, the increase in the distance between the bolt circle and the exterior of the pipe has to be specially taken into account in deciding the thickness of the flange.

It is for this reason that in the British Standard Tables of Pipe Flanges the thicknesses for steel or wrought-iron flanges welded on are made the same as for cast-iron flanges, notwithstanding the much greater strength of the flange material in the former case.

In dealing with this question, it is quite realized that if the necessity did not arise for coupling up pipes with welded flanges, to valves or cast metal tees, etc., smaller flanges could be used on such pipes with advantage. The Tables thus include one specially elating to welded-on flanges intended for use on long pipe-lines

free from valves, etc. In this case the dimensions of the flanges are similar to those in the other standard Tables for steam pressures of from 55 lb. to 325 lb. per square inch, but for 2-inch pipes and upwards, the sizes of flanges used are those for the next smaller sizes of pipes in the other standard Tables. Thus the pipe-line size of flange for a 6-inch pipe is that for an ordinary 5-inch, and so on.

Jointing Material.—The sub-committee did not make any recommendations as to packings, though they discussed these. The author would, however, like to point out that the strength of a flange is much greater if the packing extends over the whole face. Packings that only extend over the surface inside the bolts throw an unnecessary stress on the flange and tend to cup it and cause it to break away from the pipe.

Some manufacturers hold that, by using their own standard sizes of flanges, they influence their customers to come to them for renewals and additions of plant; but as they must also be prepared to supply to British standard sizes, it is probable that any advantage they gain by retaining their own standard is counterbalanced by the extra cost of using two standards.

In cases of breakdown the enormous advantage to large users of machinery, of a standard, cannot in general be over-estimated. Fittings of subsidiary machinery can in emergency be transferred to the most important uses. Spares are fewer and more generally useful, and renewals can often be obtained from stock; whereas special flanges require special fittings throughout, and this, in the case of cast-steel, involves a delay of weeks, that may be serious.

The British standard for pipe flanges is certainly the most largely adopted at the present time, and it is suggested to those members of the Institution who have not already adopted it, that they should give the matter their careful consideration.

The author wishes to thank the Engineering Standards Committee for the permission granted to him to quote from the Reports issued by that Committee; and he is much indebted to Dr. Maw for his assistance in the preparation of this Paper.

The Paper is illustrated by 5 Figs.

Discussion.

The CHAIRMAN (Mr. Michael Longridge, Vice-President) said he was not surprised that the author and his Paper had been received with applause, because both appealed to instincts and propensities in which most men were fond of indulging. The author, like the Irishman at Donnybrook Fair, had taken off his best coat and trailed it behind him for people to stamp upon and try to tear to pieces. The Paper, in addition to describing the method by which the Engineering Standards Sub-Committee on Pipe Flanges had gone about its work, and giving the Members a difficult theoretical problem to solve at the top of page 88, had also given, to those who had not been concerned in the preparation of the Sub-Committee's Report, an opportunity of explaining how much better they could have done the work if it had been committed to them. He believed the present was the first time that a Report of one of the Engineering Standard Committees had been deliberately put up as a target to be fired at, and if the Report in question stood the fusillade of the Members of the Institution, he thought it might be reasonably concluded that the recommendations the Committee had made were the best that could be suggested under the circumstances. If, on the other hand, valid and serious objections were taken to their recommendations, he was quite sure the Committee would take these objections into serious consideration at the next annual revision of their Report.

The Resolution of Thanks was then put and carried with acclamation.

Dr. WILLIAM H. MAW (Past-President), in opening the discussion, said the author had given a plain and straightforward statement of the work of the Pipe Flanges Committee, and there was very little to add to the Paper so far as an account of their work was concerned. There were, however, several very interesting points in the Paper which were in the nature of by-products. Some of these related to

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the experiments made by Mr. Dewrance on the flanges of a $2\frac{1}{2}$ in. bronze pipe.

Referring to the tests illustrated by Figs. 2 and 3 (page 87), Dr. Maw remarked that the experiment on a segment of the flange which had been isolated by saw-cuts, as shown in Fig. 3 of the Paper, was marked by some very interesting features. In the case of a straight flange, if a certain length, bolted up by, say, three bolts, required a load of 9 tons to produce a given distortion, then if the flange was divided into three parts by saw-cuts midway between the bolts, it would still require a total load of 9 tons, or 3 tons per bolt, to produce the same distortion, as it would have been simply divided into three cantilevers with parallel sides. Such a flange might be regarded as representing the flange of a pipe of infinitely large size. But in the case of ordinary pipe-flanges, the division into segments by radial saw-cuts produced cantilevers the width of which diminished inwards, as shown by Fig. 3 and on the left-hand side of Fig. 6. In the case of the particular flange tested by Mr. Dewrance, the pitch of the bolt-holes was $2\frac{3}{16}$ inches and the width of the isolated segment at its root was $1\frac{3}{16}$ inch, or 54 per cent. of its width at the bolt circle. Now, the uncut flange required a load of 19·2 tons, or 2·4 tons per bolt, to produce a permanent set of $\frac{1}{8}$ inch, while in the case of the isolated segment the same set was produced by a load of 1·27 tons. But 1·27 ton was 53 per cent. of 2·4 tons, so that they had the curious result that the fact of the flange being uncut enabled it to offer a resistance practically equal to that which would be offered by eight segments, if it were possible for these segments to have parallel sides and a width equal to the pitch of the bolts. This showed the possibility of the uncut flange acting as if it were made up of a series of overlapping cantilevers, as indicated on the right-hand side of Fig. 6. If this were assumed, then the portions of the flange metal indicated by cross-hatching would be subject to compound stress, tending to produce distortion in different places.

If this assumption approximately represented the actual facts, it would follow that the portions of the flange outside the contour

of the imaginary overlapping cantilevers might be cut away without affecting the strength of the flange. At the suggestion of the speaker, Mr. Dewrance kindly arranged to make an experiment on this point, and the tests of the flange shown in Fig. 4 (page 88) were the result. This "starfish" flange, as it might be called, gave a permanent set of $\frac{1}{8}$ inch with a load of 15·27 tons, while a circular flange, having a diameter equal to that of the "starfish"

FIG. 6.

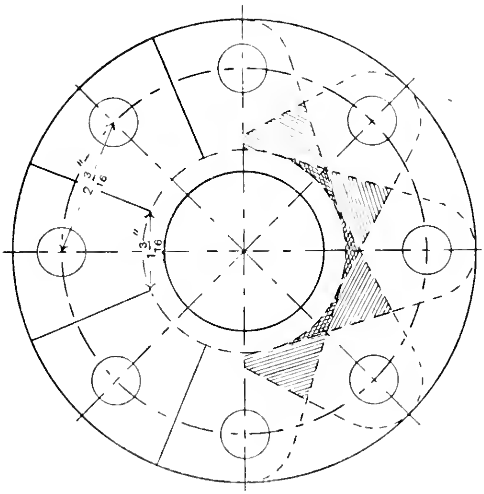
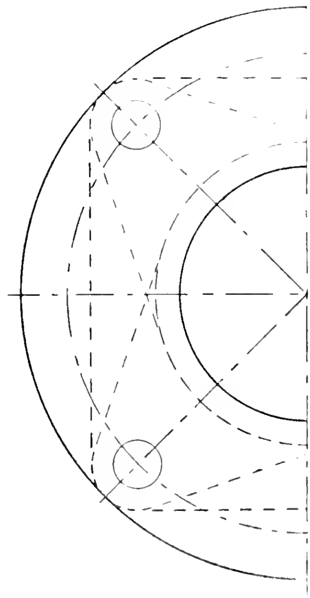


FIG. 7.



flange over the points of the rays, required 16·99 tons to produce the same set. In this case, therefore, there was a loss of strength of 10·3 per cent., due to the cutting away of portions of the flange, but the weight was reduced in a far larger ratio. The starfish-shaped flange shown in Fig. 4 was, he thought, cut out a little too much, and a very slight filling up of the curves in the hollows of the flange would probably have given it the full strength of the round flange.

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The point to which he had called attention had a bearing on the success with which square flanges were used. One of the troubles experienced by the Committee, in drawing up the Standards, was that of getting people to believe that four bolts were sufficient for a 2-inch flange. This was rather curious, because there was an enormous number of flanges for 2-inch pipes in use in this country with only four bolts. Practically all the locomotive feed-pipes had flanges of that kind, and not only that, but English locomotive engineers for many years had been using regularly four bolts on 4-inch and 4½-inch steam-pipe flanges. On looking into the matter, it seemed to him that this practice constituted a corroboration of the strength of the starfish pattern of flange. Fig. 7 (page 93) represented half a circular flange for a 4-inch pipe with only four bolts. It looked rather an undesirable thing to use, but if portions were cut off so as to give it the square form, also shown on the diagram, it looked much less objectionable. It would be noticed that the square flange sufficed to include the imaginary cantilevers to which reference had been made, and that the portions of the round flange cut away were superfluous. It seemed as if that result had been arrived at in practice by experience and not by any scientific reasoning. In the case of a flange with eight bolts, cutting away of the metal outside the imaginary cantilevers, to which he had referred, gave the form of flange which the author had illustrated in Fig. 5 (page 88).

He desired to refer to only one other small point, namely, the bronze pipe illustrated by Mr. Dewrance in Fig. 2 (page 87). It was worth notice that the pipe shown was quite a symmetrical one, the flanges at the two ends being alike, but one was bolted up tight to a thicker flange, and the other was separated from what he might call the testing flange by a space. In the experiments referred to, the loosely coupled flange to the left-hand side of the Figure was distorted, but the other was practically undistorted, although it had the same stresses on it. The author specially mentioned that the flange on the right-hand side was undistorted, and that he used it for another experiment later on. He wished to say, in conclusion, that he quite corroborated the Chairman's

statement as to the desire of the Pipe Flanges Committee to have the fullest possible criticism of the work they had done. The Committee had held a great number of meetings, and had put a great deal of hard work into the matter. It was very gratifying to be able to state that last year the Committee received a letter from, he thought he might say, the largest pipe maker of the country, saying that his firm was now making 75 per cent. of its output of steam-pipe flanges to British Standard dimensions.

Mr. WILLIAM H. PATCHELL (Member of Council) said he would prefer to have heard what the members present had to say on the Paper before he spoke on it himself, not only because he was on the Committee, but, as the Chairman had said, the present was perhaps the first time that one of the British Standards had been put up to be shot at. Had it been put up for that purpose when the Standard was new, something might have been said for it. He thought probably the reason for airing the matter at the present time was to bring one or two dissentients into line, because the Pipe Flange Standard had probably received nearer universal acceptation than any other of the British Standards. The author knew more about the Admiralty than he (Mr. Patchell) did, but he did not know whether the Censor would permit him to say what it was now doing in respect of pipe flanges. The last he heard was that they were not quite in accord with the British Standards.

Dr. Maw had referred to Fig. 2 (page 87), in which the tightly coupled flange stood, while the loosely coupled flange buckled. That, he thought, was due to the outer edge of the tightly coupled flange being kept in position, as it would have to go forward if the flange dished. The point that Dr. Maw referred to, with regard to the strength of the flanges, appealed to him more on the question of the joints. The worst part of a flange was the joint which had to be made in it. Some people were only concerned in making or selling flanges. At the time that the Pipe Flanges Committee was sitting he was engaged in buying flanges and using what he bought, which was sometimes an unfortunate position for putting one "in

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the know." The experience he then obtained was that the thin flanges which were then the ordinary stock did not stand up to their work.

The author had referred to the advantage of putting the packings entirely over the face of the flange. That, again, was a point which appealed in one way to the man who was selling the flange and had to pay for the transport of it, and who would like to make the flange a little thinner, but it appealed in another way to the man who had to work the flange. An ordinary way of erecting pipes was to bolt them up in position, take out the top bolts, and drop the jointing material in, and if the joint had to be made all over the flange, it was a very different matter. So far as the use of jointing material was concerned, the ideal joint was metal to metal, scraped joints, but unfortunately they were too expensive. The author referred to some tests which were made for the Standards Committee on red lead which was baked. That approximated to the ordinary commercial joint. The Taylor ring was used perhaps more than that method, but it was often abused by the corrugations of the ring being blocked up with something which would not yield. It was sometimes advisable to use a material which did not bake hard, but retained a little flexibility. Many years ago it was possible to get a flexible sort of cheap rubber for the purpose. With such joints, after the main had been let down cold, it would leak a little when the steam was turned on, but it very soon warmed and would take up. At a subsequent date he bought what was sold as the same material, but he found that after letting the main cool, leakage took place when steam was put on again. He then ascertained that the material had been altered in its manufacture, and by being baked had lost its resiliency.

The author might, he thought, have given further details in connexion with the tests of the flange mentioned on page 87, as an interesting record existed with regard to that matter. As Dr. Maw had stated, it was doubted whether four bolts would hold up for a 2-inch pipe. He believed the Americans went up to $2\frac{1}{2}$ inches for four bolts, whereas the English practice was to draw the line at

2 inches for four bolts. At the time to which he referred, the author made some tests, a short reference to which might be useful and permissible. The tests were of $2\frac{1}{2}$-inch bronze flanges, $7\frac{1}{2}$ inches diameter, $\frac{3}{4}$ inch thick, with four $\frac{3}{4}$-inch bolts, on a $5\frac{7}{8}$-inch bolt circle. First with joints turned only. With a Cooperite joint $\frac{1}{16}$ inch thick inside the bolts, leakage occurred at 1,500 lb. pressure; with red lead heated before testing to 380° F. for 12 hours, leakage occurred at 200 lb. pressure; with a corrugated ring thickly coated with plumbago stuck on by spirit varnish, leakage occurred at 1,700 lb. pressure; with a corrugated ring thickly coated with plumbago stuck on by spirit varnish, but heated to 380° F. for 12 hours, the leakage occurred at 1,200 lb. pressure; and with plumbago stuck on with spirit varnish inside the bolt circle, leakage occurred at 50 lb. pressure.

Then the author carried out some experiments on similar flanges turned and scraped to a perfect surface inside the bolt circle and eased off beyond. With four $\frac{3}{4}$-inch bolts, and Cooperite $\frac{1}{16}$-inch thick full diameter of flange, leakage occurred at 1,500 lb.; with thin red lead on the scraped surface it occurred at 350 lb.; and with thin red lead as previously stated, but heated to 380° F. for 24 hours, it occurred at 350 lb. Then with six $\frac{5}{8}$-inch bolts, with thin red lead not heated, leakage occurred at 1,300 lb.; with thin red lead heated to 380° F. for 24 hours, at 1,350 lb. Further tests with eight $\frac{5}{8}$-inch bolts with thin red lead not heated, leakage occurred at 1,700 lb.; and with thin red lead heated to 380° F. for 24 hours, at 1,750 lb., so that the result with six bolts instead of four on a $2\frac{1}{2}$-inch flange gave a minimum of 1,300 lb. Those figures were, he thought, rather useful as showing how joints might be made. About the same time the Admiralty made some tests on 12-inch and 15-inch flanges. The flanges that were available were not thick enough to stand up to the work; they all leaked in the preliminary tests at 500 lb., and the best of them stood 600 lb. Instead of waiting for further flanges, those particular flanges were cambered so that when two were put together there was a gap of $\frac{1}{32}$ inch at the outside edge. A 12-inch flange under those circumstances stood 1,100 lb. pressure, and the 15-inch which had

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failed at 400 lb. when flat, failed at 900 lb. That showed how the best could be made of a bad job; but he would not recommend anyone to buy cambered flanges.

He hoped the Institution would hear what objections there were, if any still existed, to the adoption of the British Standard flanges, because everything was to be said in favour of a uniform standard. Nothing was more annoying, if an engineer was buying a piece of machinery, than for him to have to telegraph at the eleventh hour, especially nowadays, when the question of prompt delivery was of the utmost importance, asking if the flanges were British Standard size.

Mr. E. J. Fox thought the Chairman was quite safe in inviting engineers to criticize the efforts of the Standards Committee on the subject of flanges, as the standards had been largely adopted both by manufacturers and users and had proved a success. Speaking as the representative of the largest firm in this country manufacturing this class of material, he could say that, with one exception to which he would refer later, the dimensions of the Standards Committee had been adopted and were their (Stewarts and Lloyds') Standards. The Admiralty and Marine Engineering firms had, however, not adopted these standards. With those two exceptions, users were largely adopting the dimensions of the Standards Committee, from which he presumed that every manufacturer was also working to them. The particulars contained in the Report laid down dimensions which were economical from a manufacturing point of view. The size of joint was as cheap as it was possible to make it for the duties specified.

Those of the members who were not thoroughly familiar with the details of the Report would be interested to know that one Table, namely, Table 2, contained the dimensions of steel flanges for use in connexion with steel pipes, and the thickness of those flanges was the thickness of cast-iron flanges. At first sight it might appear that steel flanges might be made a good deal thinner than cast-iron, and to some extent he personally thought that that was the case: and certainly many engineers were willing to accept

lighter flanges. But the point to which the author had referred was that a flange, however strong in itself, when attached to a comparatively thin body was liable to "give," and consequently was not as rigid as a cast-iron flange on a cast-iron pipe. For that reason the dimensions given in Table 2 were those in use for cast-iron flanges. But as an alternative a further Table, namely, Table 3, was introduced, in which smaller dimensions were adopted for steel flanges for use in those cases where the flanges were welded on the steel pipe.

He desired to take the present opportunity of slightly departing from the direct subject of the Paper to emphasize the great superiority of steel flanges welded on steel pipes over steel flanges either screwed on or riveted on. From the point of view of obtaining a satisfactory joint, if the dimensions of the flange were kept down in diameter and in thickness, as set out in Table 3, it followed that a stiffer joint was obtained; further, he thought most engineers were now agreed that the welded-on flange made a more satisfactory joint when compared with a flange riveted on or screwed on. It was advisable, however, to avoid a plain parallel flange: and it was equally important to avoid a flange with a large boss on it. The medium between the two, that is, a large fillet on the back of the flange, was really the ideal, and represented the best practice at the present time for flanges to be welded on pipes.

He now came to the important exception, to which he had already referred, where it had been found difficult—indeed, he might say, from a commercial point of view, impossible—to work to the standard dimensions, namely, in connexion with steel pipes with loose flange-joints. Loose flange-joints, as members knew, represented an important portion of the steel-pipe trade. It was not unusual to get lines of steel pipes with loose flanges up to 40 and 50 miles in length. The Standards Committee had adopted, quite rightly as far as practice generally was concerned, multiples of four for the number of bolts in flanges. The old practice, however, in connexion with loose flange-joints had been multiples of two, and in so far as loose flange-joints were generally used in long lines where valves, fittings and special material of that description

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was not much used, it mattered comparatively little whether the dimensions set out in Table 2 were departed from, and consequently the old standards were retained. He did not know whether he had made the point quite clear. The loose flange-joint was the cheapest form of joint possible in connexion with steel pipes. It was the cheapest form, because it enabled the use of a thinner pipe than where a flange was rigidly attached either by welding or riveting to the pipe itself. And as cheapness was the primary consideration, the new standards were not adopted in connexion with this class of pipe.

He asked permission to refer to one point in passing, because, although it was not directly concerned with the subject matter of the Paper, it was of interest. Flanges, after all, were merely a means of joining together two pipes. The application that had been introduced during the last two or three years of welding together by oxy-acetylene two lengths of pipe on sight and displacing other forms of joint, including the lead joint, was an application that was likely to be extended very considerably in the future. It gave practically the only form of joint which was as strong as the pipe itself, and which on a tensile test would more often than not break off the joint, which was as cheap as the ordinary lead joint where gas was available, and which was permanent. It was easy to make other forms of joint which were tight when made, but which were liable to start leaking in the difficult conditions of traffic under which joints had nowadays to work. In conclusion, he felt, speaking on behalf of a manufacturing firm, that they owed a debt of gratitude to the Standards Committee, with which the author and Dr. Maw had been actively associated in standardizing pipe flanges, for having given manufacturers standards to which to work.

Mr. H. F. Rutter said that as a user of flanged work he desired, in the first place, to bear testimony to the immense advantage and convenience which had accrued since the use of standard flanges had become general, and he felt sure engineers could look forward to the time when that use would become universal. His object in

rising was to make a suggestion to the author, for his consideration and conveyance to the other Members of the Committee: it was that they should extend the list of flanges in regard to which they had already laid down standard dimensions. The largest flange with which the Committee had dealt up to the present time was a flange suitable for a pipe of 24-inch bore, but that did not go far enough. For steam purposes, especially in the present day of superheat and consequent small steam-pipes, it might be far enough, but engineers, who had to deal with water, had to use pipes of very much larger dimensions. They experienced very frequent inconvenience from the fact that there was at present no uniformity among the makers of stop-valves, reflux valves, and other fittings of that sort, with the result that they were put to the inconvenience of drilling bolt-holes on the ground, whereas they might just as well have been drilled under a machine. He therefore suggested to the author that the sizes of pipes dealt with should be extended to include the following:—30, 33, 36, 42, 48, 54, and 60 inches.

Mr. J. Arthur Aiton said it spoke well for the work of the Standards Committee that there was very little to criticize after ten years' usage of the Standards that they had prepared. The members had been told that the largest maker of steam-pipes made 75 per cent. of them to Standard dimensions, and they had heard that another of the largest makers, who said he was the largest maker, made all his pipes to Standard. Personally, he made a few steam-pipes, and when an application was made to him for anything outside the Standard, he charged extra because it cost more to make.

With regard to the various Tables that had been given in the Standard specifications, he desired, if he might be so presumptuous, to suggest that in Table 2, columns 7, 8 and 9 should be entirely cut out, for the following reasons. He did not think that a body, of the standing of the Engineering Standards Committee, should countenance such an antiquated and out-of-date thing as cast-iron for steam-pipes. Furthermore, they had heard what the author had said about welded pipes, which was the other direction in

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which those particular columns were used. So far as his own experience went, he wished that the Standards Committee had stated plainly that the column to which he referred was for flat welded-on flanges and not flanges welded with a collar. Despite what one of the previous speakers had stated, he knew that flanges with a collar were very successfully welded on to pipes. It was purely a question of the method of welding. If the welding were done by what was called the fire process—that is, heating the flange and the pipe in a fire and hammering—he did not think any more successful method could be adopted than to have a good stiff collar on the flange; but if the welding were being done by the electrical or any other process, then he quite agreed that the collar was not an advantage at all.

He thought the oxy-acetylene method was never used for such heavy work as the welding-on of flanges, but if the electric method were used, a very large and ample fillet ought to be provided, for two purposes. In the first place, it allowed for an extra amount of metal. He did not think that even the strongest supporter of electric welding would say that the metal which was deposited was equal to the metal of the pipe or the flange, and it therefore allowed a large amount of metal to bring up the strength of the joint by an amply heavy fillet—he did not mean a small thing about $\frac{3}{8}$-inch radius, but a heavy fillet. That stiffened the back of the flange, and it brought the flange almost up to the state of a flange with a big collar on it; furthermore, the position was raised up where it was being attached to the pipe. The attachment of a heavy flange to a light pipe was strengthened, a point which had been raised by one of the previous speakers. For those reasons he suggested that the three columns to which he had referred were unnecessary, and led to confusion.

He had personally experienced a considerable amount of confusion through engineers specifying the Standards Committee's dimensions, and when they were given the figures in column 11, they replied that they expected to get the figures in column 8, and it was then necessary for the manufacturer to point out that that column referred to a flange without a collar on the back of it. He

further suggested that the Committee should leave out all the starred sizes except $4\frac{1}{2}$ inches, because the other sizes, 9, 11, 13 and 17 inches, were bastard sizes that could very well be dispensed with. Table 1 was very good so far as it went, but engineers had advanced in the last ten years, and it did not now meet all the purposes required. Mr. Rutter mentioned that it did not meet the purpose of large water-pipes, and it certainly did not meet the purpose of large low-pressure steam-pipes such as were used with turbines. Those pipes were made up either by riveting or by welding, and the flanges usually consisted of a rolled-up ring of angle-bar either riveted or welded to the pipe. He would not suggest that the test pressure required for those pipes should be more than 30 lb., and therefore those flanges could and would have to be kept thin because of the method of manufacture. It was difficult to obtain those flanges more than $\frac{3}{4}$ inch thick. He suggested that it was not necessary in those flanges to increase the size of the bolts, as was done regularly as the sizes went up, and he contended that a 1-inch bolt was ample for all purposes, even up to 72-inch flanges. It was only a question of putting in enough of the bolts. He suggested that the circumferential pitch-circle should in no case exceed 7 inches; $6\frac{1}{2}$ inches was about enough. With thirty-two bolts on a 60-inch pipe, a pitch of about $6\frac{1}{2}$ inches would be obtained, which he did not think would be excessive either for the number of bolts or for the pitch, and he thought a very satisfactory joint would be made in that way $\frac{3}{4}$ inch thick.

With regard to the vexed question of jointing material, he was perhaps treading on rather dangerous ground, especially after what had been said by Mr. Patchell, who suggested that it was the contractor's business to put up the pipes and get rid of them. His experience as a contractor was that neither Mr. Patchell nor any other engineer would let a contractor off who erected such work quite as easily as that. There was such a thing as reputation to be considered; and it was not worth any contractor's while to put up a set of pipes which leaked at the joints continuously after he had done with them. It had been his practice for many years only to use joints inside the flange, and that was done of "malice

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aforethought." He did not consider that putting a joint all over the flange strengthened the flange in the very least—that is, if a flange was going to cup, it would cup whether there was a joint all over it or not. The only difference, to his mind, was that if it cupped with the joint inside the bolt-holes, it would tighten the joint, whereas if it cupped with the joint outside the bolt-holes—that is, if it cupped through the stress of its work—leakage would be obtained between the pipe and the bolt-holes, which was just as bad as if it were obtained through the flange entirely. His experience of the use of Taylor rings was that they were very satisfactory—in fact, 95 per cent. of the joints which he supplied were Taylor rings; but, like everything else, they must be used with discretion. One of the great faults with those rings was to put a heavy mastic joint on them; in his opinion, they should be painted. The jointing material, which should be put on with a brush, should be quite thin. If a joint of heavy putty were put on, it defeated the aims of the rings entirely, because they could not then be compressed. The stiff putty was locked up within the corrugations, the joint thereby being made inefficient, whereas if the joint was simply painted it had a chance of "squashing" up and doing what was required.

One of the previous speakers had referred to the oxy-acetylene welding of pipes in position. He had had no personal experience of that operation, and had always avoided it, because he was afraid to use it. His own experience of oxy-acetylene welding was that to make a satisfactory weld, the welding position must be on the top or near the top of the pipe, and he had never yet been able to understand how anybody could weld successfully, by the oxy-acetylene process, a range of pipes which had bends in it which could not be turned round. He had heard of that being done, but he did not believe it could be accomplished successfully, and he would be very sorry to trust his life to such a weld.

So far as the Paper was concerned, he would perhaps be excused for saying that he was disappointed with it. As a historical Paper of what was done ten years ago it was most interesting, but he did not think the historical point of view was the object with which the

Paper was written. He thought that a great opportunity had been missed, because there were so many vexed questions in connexion with steam-pipes that might have been raised. For instance, there was the old argument as to whether lap-welded or solid-drawn pipes should be used, and also the question of the thickness of the pipes. A little had been said that evening about the method of fixing the flanges and the question of the jointing material, while the question of the method of fixing branches might also have been discussed. So far as the fixing of branches was concerned, ten years ago oxy-acetylene and other forms of welding were very much in their infancy, but nowadays the use of cast-metal branches was practically out of date. There were only two methods at present used, namely, riveting on or welding on.

Then the question might have been raised of whether the welding should be done by the oxy-acetylene process, by electricity, by the ordinary carbon arc, or by the newer system known as the quasi-arc system. Personally he had never been able to find an oxy-acetylene joint that was up to the full strength of the plate. He had made and tested a few such joints, but he would never dare to claim that that was so. He had not even found a carbon-arc joint which was up to the strength of the plate, but with the later quasi-arc, which used a semi-arc and a special form of electrode, by the thickening of the joint which took place, he had found that the breakage occurred not at the joint but 3 inches or 4 inches back from it. By that method he had found something which was certainly up to the strength of the plate, or could be made up to the strength of the plate. He did not claim that, if it were kept to the same thickness as the plate, it would be up to the same strength, but by the deposition of metal the joint became thicker, and was therefore up to the full strength of the plate. As he had already mentioned, he suggested that the Engineering Standards Committee should devote some attention, in its revision of the Specification, to the provision of Standards up to 72 inches for use with turbines, as commonly used with riveted pipes or pipes made by various welding processes. He would like the Committee to make some statement as to what they

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considered to be the right thicknesses of pipes, because at present they varied enormously. He also thought that if this Institution could devote its attention to the question of the fixing of flanges and branches, and the other vexed questions which he had mentioned, they would be serving a very useful purpose.

The CHAIRMAN said he regretted to hear Mr. Aiton say that he preferred a joint made with a ring entirely inside the bolt-holes. No doubt a tight joint could be made that way, but he was perfectly satisfied, from long experience, that with cast-iron flanges at least, joints made in this way were dangerous. With wrought-iron or steel pipes there was less risk, but he was sure that the stresses produced by screwing up the bolts, where the support was entirely inside the bolt circle, often produced dangerous strains. He thought that Fig. 2 (page 87) proved the advantage of making the joint over the whole face of the flange, because it showed that the flange which was supported all over held good, while the flange which was not supported was deformed by the tension of the bolts.

With regard to the question of fixing flanges, he preferred welded flanges with collars, but as he had seen cases where such welds were only sound at the edges of the collars and thought it highly probable that there were many similar cases, he advocated riveting in addition to welding, so that if the welding gave way, the collars could not be drawn off the pipes.

He desired to say a word about the interesting remarks that Dr. Maw had made in regard to the relation between flanges and cantilevers. Personally, he could not see any connexion whatever between the two. If a flange became cupped, either the diameter of the outside edge of the flange must be diminished or the width of the flange radially must be increased. In the one case the material was compressed, and in the other it was stretched. In either case the resistance of the flange to deformation increased as the quantity of material to be compressed or stretched increased. In the cantilever the addition of material outside the bolt-hole would not increase the resistance to bending by a stress applied at the bolt-hole. In the undivided flange the addition of material

outside the bolt-circle would increase the resistance to cupping. The determination of the amount of this increase of strength was the difficult theoretical problem he had referred to in his opening remarks. The Sub-Committee had apparently failed to find a satisfactory mathematical solution, and had relied on experiments to determine the thickness of the Standard flanges. It would have added much to the value of the Paper if these experiments had been described. It might happen that the effective strength of the particular flange, referred to by Dr. Maw, was the same as that of a number of cantilevers whose base was equal to the pitch of the holes, but it did not at all follow that the same relation held for pipes and flanges of other diameters. He thought the points the Committee ought to have determined, and perhaps they did determine them, were, first: the best relation between diameter of flange and its thickness, and, secondly, the thinnest flange that was required to make an effective joint.

Mr. WILLIAM H. PATCHELL said that Mr. Fox had mentioned the question of welded joints. He remembered some time ago being on an undertaking where a condenser could not be placed close to a turbine and a 6 or 7-foot diameter wrought-iron exhaust pipe of some considerable length was to be welded up. The contractors got on very well with the work until a frost came on, when they found it absolutely impossible to weld the last joint, as they could not get up the temperature, and they were obliged to put on a muff joint. That opened his eyes to the possibilities and limitations of joints welded in situ.

Mr. E. J. FOX said he desired to be allowed to make a few further remarks on the subject of oxy-acetylene welded joints in connexion with steel pipes. Although the system was a comparatively new one, it had been adopted by between seventy and eighty gas and water undertakings in this country during the last two years, so that any practical difficulties had been overcome. One of the previous speakers had mentioned the subject of welding underneath. That was a difficulty which it took much experimenting

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to overcome. The difficulty of welding underneath, without dropping down the soft Swedish iron which was used as a welding material, was overcome in a simple way by the shape of the socket where the spigot entered it. There was just sufficient curvature to hold the molten material whilst the welding was going on.

It might be stated that the spigot was a driving fit in the socket, and the process of welding consisted in filling in the gap in the socket with soft Swedish iron—in other words, in rigidly welding together the spigot and socket. Mr. Patchell had referred to the difficulty of making that form of joint when other pipes were in the locality. It stood to reason that this form of joint could not be made unless it was accessible, but there were few cases where this was impracticable. A lead joint could sometimes be made at a distance of a couple of feet, but that was not often necessary. As a rule, it was possible to get at the joint sufficiently closely to make it. The welded joint to which he had referred could be guaranteed as strong as the pipe itself, and, as already mentioned, was more likely than not, on a tensile test, to break off the joint.

The CHAIRMAN, in dealing with the question of welding the undersides of pieces, said he had seen a very interesting process a short time ago at Liverpool for welding up cracks in boilers in steamships. One of the terminals of the arc was the welder and the other was the boiler itself. One feature of the process was that the bits of iron which were put in were held up to the boiler by magnetism, while the welding was being carried out. It was a German process; he did not know whether it was in existence now, or whether it had gone back to Germany. Cracks, flues of the furnaces, and flanges of end plates were being welded with the greatest ease.

Mr. JOHN DEWRANCE said there were very few points to which he had to reply. Most of those who had spoken had asked if he would impress upon the Standards Committee that further work was required, and when a Committee was asked to do more work it was fair to presume that the work they had already done had been

satisfactory. Mr. Aiton suggested that he (the author) had missed a great opportunity of going more fully into the question of the construction of the different materials and the method of manufacture of pipes, but that was not the object of the Paper. As he understood it, the object of the Paper was to put upon the Proceedings of the Institution some record, belated as it might be, to the effect that the subject had not been allowed to rest as it was left by Mr. Atkinson in the Paper to which reference had been made. It was therefore confined simply to the subject of the standardization of flanges and not to the material and construction of the pipes. The changes in material and in the uses that had taken place since the standards were fixed had been considerable, but he did not think Mr. Aiton was quite right in suggesting that the use of cast-iron for bends, tees, valves, and fittings had been entirely done away with at the present time. There were still a great many fittings that were made of cast-iron, especially for the lower pressures, and he did not think the Committee could be expected hurriedly to omit all reference to that material.

Dr. Maw had given a very interesting criticism on the subject brought forward in the Paper as to the strength of the flange, but Mr. Longridge had practically supplied what he (the author) intended to say in answer to Dr. Maw. He did not think Dr. Maw intended the members to go away with the impression that the flange was entirely without strength, because that would be almost the inference of the figures Dr. Maw had given. There was no doubt it took a certain amount of power to cup the flange, and something must be allowed for it.

Mr. Longridge asked how the Committee determined the thicknesses of the flanges. All the determinations were empirical. He did not think there was any case in which they failed to get some member of the Committee or some body to make tests for them in the way explained in the Paper. Right up to the 24-inch size, if his memory served him correctly, actual experiments were made. It was rather amusing to him to remember that, to begin with, the Committee was bitterly condemned by the pipe-makers for the lavish waste of material they suggested should be put into

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the flanges. Their critics were ultimately induced to attempt to prove to the Committee how stupid they were, and they carried out some very costly and interesting experiments to show how excessive the thicknesses were. But the result of the experiments had the effect of converting the makers entirely; indeed, in one or two instances they suggested that the Committee should still further thicken the flanges, because it was quite clear that those which had been in use up to that time could not possibly be kept tight without some elastic packing, which, as all the members knew, was unsuited to superheated steam.

The suggestion which had been made, that Standards should be drawn up for larger pipes up to 60 inches, he would report to the Committee at the first opportunity, but he thought it was a little beyond the scope of the work they undertook at the time. Such large pipes would be used more for water purposes, whereas the Committee had steam-pipes and general pipes under their consideration. He thanked the members very much for their reception of the Paper, and for the discussion that had been raised on it, and he hoped there were not any very severe critics who had been kept away from the Meeting by the bad weather.

Communications.

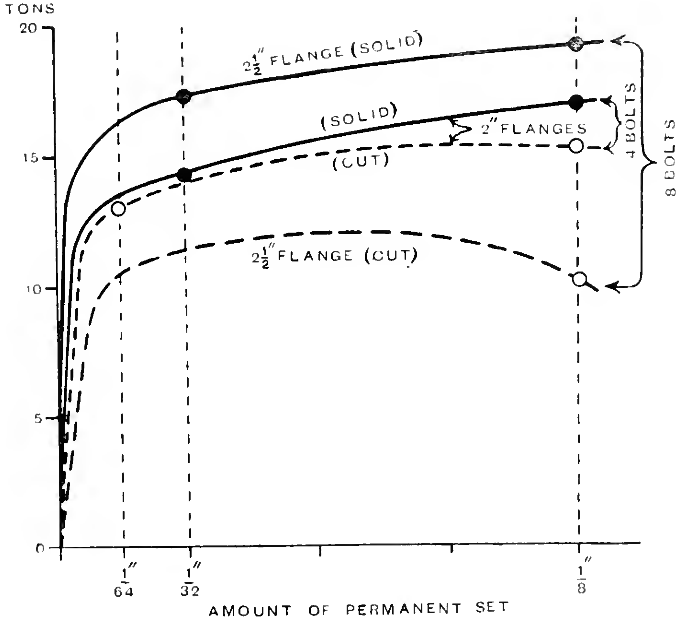
Mr. C. Humphrey Wingfield wrote that, like all Mr. Dewrance's communications, this Paper was very interesting. He gathered that the author had no intention of raising a discussion as to the propriety of the conclusions reached by the Engineering Standards Committee, but rather of drawing attention to them, and showing the adequacy of the proportions recommended in their Report.

The author's experiments showed that when metal was removed from between the bolts in order to reduce weight, this might be done to a greater extent where the bolts were widely pitched than where they were close together. In each case the "bracket" of metal carrying the bolt should increase in width as it approached the pipe (*see* Figs. 4 and 5, page 88).

He had plotted the author's experiments in Fig. 8, adding

lines (the precise form of which, of course, had no special significance) to connect the dots and show their relative heights. This diagram showed how much less the strength was affected by cutting away the metal of the flange with four bolts, in which the width of the bracket increased as it approached the pipe, than in the case of the flange with eight bolts, Fig. 3 (page 87), in which the reverse was

FIG 8..



the case. In the latter the loss of strength was $\left(100 \times \frac{10 \cdot 16}{19 \cdot 2}\right)$, or about 53 per cent., whereas in the former it was only $\left(100 \times \frac{15 \cdot 27}{16 \cdot 99}\right)$, or about 9 per cent. The indentations shown in Fig. 5 (page 88) were of practically identical proportions with some with which he was familiar some 30 years ago, and he might say that no trouble had been met with on the score of strength. They were, however, open to the objection that, when two flanges of the same size were bolted together, their angular position did not always

(Mr. C. Humphrey Wingfield.)

agree exactly,* and a certain amount of chipping became necessary for the sake of appearance, and it was found advisable to avoid this by casting one flange slightly larger than the other. In some instances one flange was circular, as suggested by the author.

The writer had not met with the suggestion (page 88) that the thickness of a flange should be determined by the strength of the metal between the bolts, regarded as a beam. The late Mr. Thomas Box had pointed out that, in the riveted seam of a boiler, the space between rivets might be regarded as a beam, the flexure of which would allow of leakage, and was of opinion that for equal freedom from leakage (pressure and other things being the same) the thickness of plate should vary as the fourth power of the width between the sides of adjacent rivet-holes. He did not know if this was what the author had in his mind. It was a case of rigidity rather than strength, and would not apply to flanges jointed with a more or less yielding material.

If ordinary flat flanges were referred to, he was in full agreement with the author's statement that the mere strength of a given flange was much greater if the packing extended over the whole surface. A specially designed flange adapted for a narrow joint could, however, be made with a smaller weight of metal than a flat one would have to be, when very high pressures had to be resisted without leakage. Fig. 1 (page 85) was one instance of this, and he knew of steam-pipe joints which had to stand a pressure of 250 lb. per square inch, to which the same remark applied.

Mr. James Norman sent a drawing of a proposed joint for a 6-inch high-pressure water main. This scheme was intended to do away with flanges and bolts by using a right and left thread twin breech-block joint. The drawing showed that the threaded ends of the pipes were drawn together by turning the enclosing breech-block-coupling through one-sixth of a revolution.

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* For instance, if the flange on the discharge branch of a circulating pump were bolted directly to a flange on a condenser, their relative angular position could not be adjusted as in that of a length of piping.

DISTRIBUTION OF HEAT-ENERGY AND FRICTIONAL LOSSES IN INTERNAL-COMBUSTION ENGINES.

BY PROFESSOR JOHN EUSTICE, B.Sc., A.R.S.M.,
OF UNIVERSITY COLLEGE, SOUTHAMPTON.

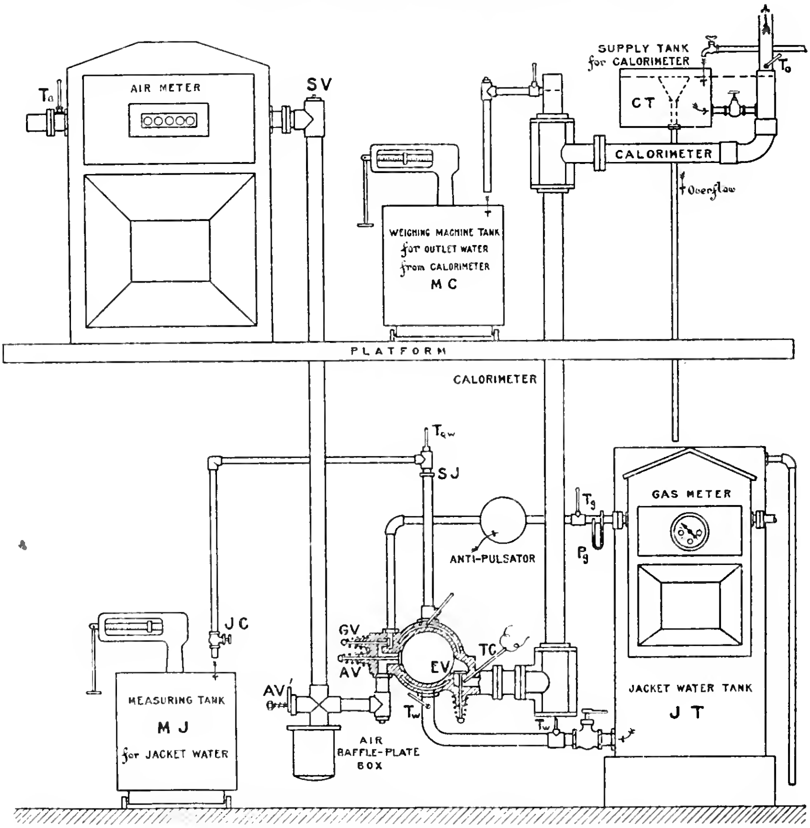
[*Selected for Publication only.*]

12 *Introduction.*—The object of the investigation was to analyse, by experimental methods, the distribution of the energy used in a gas-engine, and as far as possible to allocate to the various moving parts the frictional resistances pertaining to those parts. The results, which are here summarized, bear only a very small proportion to the work done, and the experimental data obtained, much of which, whilst applicable to the engine used, may not be of general application. It is hoped, however, that the results which are given in the following summary may be useful in showing, not so much the actual values of the frictional losses in other engines, as the relative proportions of the losses. The rate of variation with the variation of speed would, for example, hold good in other engines, whether larger or smaller than the engine which is described below.

The author desires to express his gratitude to several of the engineering students of the University College of Southampton for their assistance; to Mr. G. P. Ford for his careful records of observations, extending over several years, and for his assistance in the preparation of illustrations. His special thanks are due to Mr. A. H. Burnand (*Associate Member*), a former colleague, both for his assistance in many of the tests and for suggestions made during the progress of the work.

Description of the Engine.—The engine used is one of Crossley's "Otto" horizontal gas-engines, piston 6·68 inches diameter, stroke 15 inches. The gas supply is controlled by a hit-or-miss striker

FIG. 1.—*General Arrangement of the Measuring Appliances.*

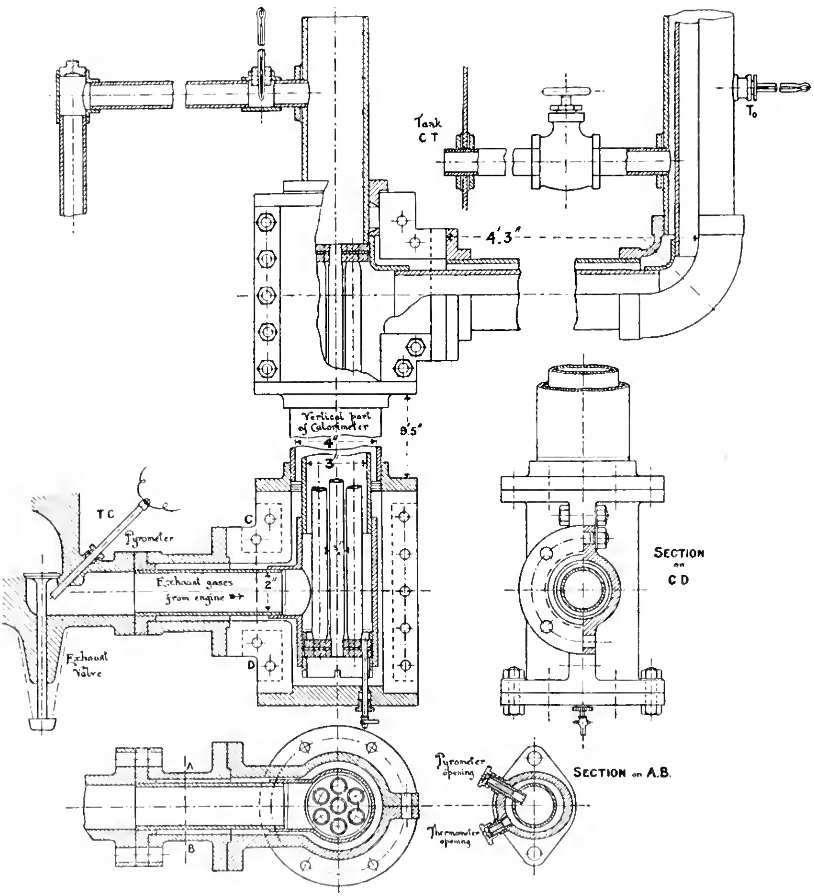


actuated by a sensitive loaded ball-governor. The fly-wheel is specially heavy, being fitted for steady running.

Special Attachments for the Experiments.—The general arrangement of the measuring appliances is shown in Fig. 1. Both the gas and

the air supplied to the cylinder could be measured by meters arranged as in the diagram. The gas supply was taken from the town mains, through a special meter; this meter was carefully

FIG. 2.—*Exhaust Calorimeter.*



calibrated and compared with the wet meter which was used in the determinations of the calorific value of the coal gas. The air-meter was brought into use by turning the three-way valve

AV′, which was constructed so as to minimize the effect of any explosion which might occur in the air-supply pipe. The cooling water for the jacket came from a tank JT, and its temperature was measured by means of thermometers inserted in the supply pipe; the outlet pipe was swivelled at SJ, and the flow of water regulated by a cock JC near the measuring tank MJ, in which the water was periodically weighed.

The exhaust gases from the engine cylinder passed into an exhaust calorimeter of special design, which is illustrated in Fig. 2. A platinum and platinum-rhodium thermo-couple TC was inserted into the exhaust pipe as close as possible to the exhaust valve; by means of this couple the mean temperature of the exhaust gases was determined as they left the engine. The temperature of the cooled gases was taken in the exhaust pipe at the outlet end of the calorimeter by means of a mercurial thermometer T_o. The cooling water for the calorimeter was supplied from the water mains of the town, after passing into a small tank CT, Fig. 1, provided with an overflow weir.

Exhaust Calorimeter.—The exhaust calorimeter, Fig. 2, is made up of a main vertical part and two subsidiary horizontal parts. The vertical part consists of two concentric wrought-iron pipes. Inside the inner pipe are placed seven $\frac{3}{4}$-inch condenser tubes which are kept in position at their ends by two perforated disks at each end; between the disks is a sheet of packing, and a screwed ferrule presses the packing against the tubes, thus making the joint water-tight.

The exhaust gases pass into the calorimeter through the horizontal pipe; they then come in contact with the outer surface of the condenser tubes and the inner surface of the 3-inch vertical pipe. After passing through the top horizontal pipe the temperature of the gases is reduced to within a few degrees of the temperature of the atmosphere.

The circulating water, which enters near the outlet end of the upper horizontal pipe, passes through the annular space between the two horizontal pipes, and thence into the annular space between

the vertical pipes, flows down to the bottom T-piece, whence it comes up through the condenser tubes to the top of the vertical part of the calorimeter, and overflows into the measuring tank MC, Fig. 1. By this arrangement the coldest portion of the water is available for the cooling of the gases near the outlet end. It was found that there was not much difference between the temperature of the outside of the calorimeter and the temperature of the air in the room; the calorimeter was, however, covered with felt above the lower T-piece, whilst that and the parts near the engine were covered with a boiler-lagging material.

Method of Experimenting.—The usual procedure in a series of experiments was fairly regular: Each of the measuring appliances was fixed in position and tested separately; the engine was then started at the speed required for the test and workes for an hour on friction load only. Meanwhile the observers were engaged in taking trial readings; when the condition appeared to be constant the actual record commenced. The readings were usually taken at intervals of from one minute to five minutes, for about twenty to thirty minutes, under constant conditions. Immediately the test ended, the load on the engine was increased and another set of trial readings made, until the temperatures, etc., under the changed conditions became constant; readings were then recorded as before. After these precautions were taken, if any variation occurred during the test, it was generally possible to select some period in the experiment when constant conditions prevailed. If for any reason it was found that the readings were unreliable, the whole set was discarded and the test repeated. The averages of the readings were tabulated in the form given below, and from these the calculations and plottings were made.

Notes on Table 1 (page 118).—Average readings: Barometer 29·9 inches of mercury; Pressure of coal gas, 2·7 inches of water; Temperature of gas, 20° C.; Temperature of air, 20° C.; Temperature of inlet to the jacket, 14·9° C.; Temperature of the inlet to the calorimeter, 14·7° C. The average of the ratios of air to gas is 6·63.

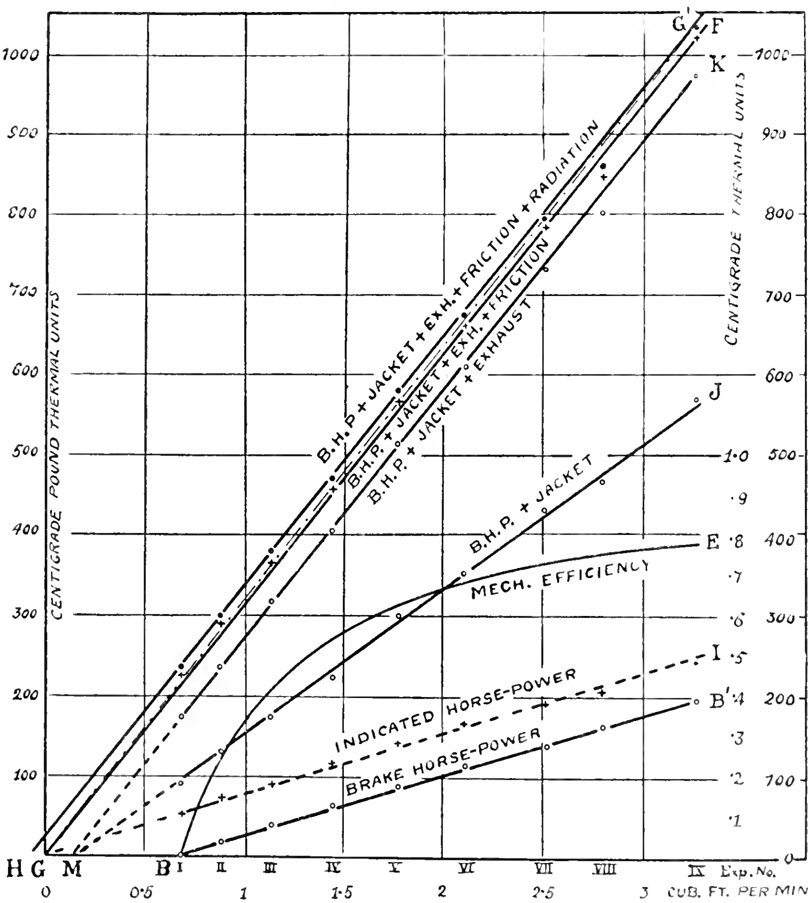
Gas-Engine Tests.

TABLE 1.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
							Centigrade pound thermal units.						
Number of test.	Revs. per minute.	Explos. Cycles.	Gas per explos.	Air per stroke.	Temp. at exhaust valve.	(t') at outlet of calor.	B.H.P. (B)	I.H.P. (I)	Jacket (J)	Exhaust (E)	Calorim C + E	Radiation (R)	I + J + C + E + R
			cub. ft.	cub. ft.	° C.	° C.							
I	201·0	0·190	0·0352	0·2319	180	2·0	0·0	53·5	90·0	0·9	82·4	9·0	234·9
II	201·3	0·249	0·0351	0·2309	210	4·2	15·2	70·3	113·0	1·9	107·9	7·0	298·3
III	200·6	0·322	0·0351	0·2305	246	3·0	39·0	91·4	134·0	1·4	143·9	8·5	377·8
IV	200·8	0·418	0·0344	0·2280	298	4·2	63·7	117·5	158·0	2·0	183·0	12·0	470·5
V	200·0	0·516	0·0345	0·2260	340	8·5	88·4	112·8	211·5	4·2	214·7	10·5	579·5
VI	199·7	0·626	0·0339	0·2265	396	8·1	113·3	167·0	238·0	4·1	256·1	9·5	670·6
VII	201·1	0·740	0·0339	0·2230	435	8·0	138·9	192·8	291·0	4·1	303·1	10·0	796·9
VIII	200·3	0·830	0·0336	0·2217	480	10·0	162·5	208·5	305·0	5·3	333·3	14·0	860·8
IX	199·9	1·000	0·0327	0·2206	536	8·3	193·2	245·5	376·0	4·5	403·5	10·0	1035·0

The average friction horse-power from the whole set of tests is 2·24 approximately; it is probable that when the friction horse-

FIG. 3.—*Distribution of Energy with gradually increasing Load.*



power is much below this, as in No. VIII, the mean pressure given by the sample diagrams is lower than the actual mean pressure.

Distribution of Energy with gradually increasing Load.—The relative proportions into which the thermal energy of the gas is divided, at various working loads, are shown in Fig. 3, where the abscissæ represent cubic feet of gas per minute, and the ordinates centigrade-pound thermal units.

The brake horse-power, represented by the line BB′, and the indicated horse-power, represented by GI, have been multiplied in each case by a constant, 23·69, to convert into thermal units. The experimental values of the thermal units given by the jacket-water are added to the heat equivalent of the brake horse-power in order to obtain points on the line MJ. When the heat given to the calorimeter is added to each of the values on the line MJ, the line MK is obtained. The line GF results from the addition of friction-energy to the line MK.

A correction is made for the heat carried away by the exhaust gases. The temperature of the inlet air and gas was nearly 20° C., the temperature of the gases leaving the calorimeter varied from 22° C. to 30° C., the difference, $t_0 - 20°$, or t', is given in Table 1, column 7. The weight of gases per minute is 1·77 lb.; the product $1 \cdot 77\ (t_0 - 20) \times$ specific heat, E in column 11, gives the heat which passes into the exhaust from the calorimeter.

Plottings of the tabulated values of heat given to the jacket show that when the temperature of the jacket is greater than the mean, the record is below the mean line. An increased temperature of the jacket causes greater losses of heat by radiation, and the gases leave the cylinder at a higher temperature; some additional heat is given to the exhaust calorimeter, the plottings from which, although more uniform than those from the jacket, confirm this statement. The mean line through the points, which give the heat equivalents of the brake horse-power, is nearly straight. In the case of similar plottings for indicated horse-power, a line through the origin passes through the points of the values obtained from the first six tests; the last three are below this line.

Radiation from the Jacket.—The fall in temperature, by radiation from the jacket during cooling tests, was obtained from cooling

curves and is given approximately by a formula:—$\delta\theta = 0 \cdot 00625 (t_w - t_a)$, where t_w and t_a are temperatures of water and air respectively. The water value of the metal in the cylinder, piston, etc., together with the water in the jacket, is about 70 lb.; the thermal units lost by the jacket per minute are given by $0 \cdot 44 (t_w - t_a)$. The losses calculated from the formula are given in column 13; taken as they are from the condition which obtains when the jacket has settled down to a fairly uniform temperature, they do not give the losses which occur during the working, except possibly at low ratios of explosions to cycles. As the number of explosions per minute increases, the temperature of the piston increases; and as this piston, of the trunk type, is moving in contact with the air outside, some of the heat is carried away; this loss is not relatively great, and it is not recorded in a cooling test of the jacket-water.

The line GG′, Fig. 3, gives the thermal units (higher value) in the gas used; this is probably correct within 1 per cent. The line HG′ from column 14, Table 1, which shows the sum of all the heat measured in the experiment, almost coincides with the line GG′ for the larger quantities of gas used, but it deviates from the line at low rates of gas used. This deviation, whilst due mainly to the meter readings, may be due in part to other causes, such as:—(*a*) The Bunsen burner is close to the engine, so that some of its heat is given to the jacket. Heat is also conveyed by the gases from the hot-tube to the cylinder; (*b*) The oil supplied for lubrication of the cylinder, by its combustion, adds to the heat developed by the engine; (*c*) The heat generated by the friction of the piston in the cylinder, and accounted for as friction work, reappears in the jacket or in the exhaust.* This apparent gain of heat, at low loads, has been observed in nearly all the series of tests.

Efficiency of the Engine.—The mechanical efficiency of the engine may be expressed by the ratio of the ordinates of the lines which give the b.h.p. and the i.h.p. The efficiency curve is represented by the line BE in Fig. 3 (page 119).

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* Dugald Clerk, Proceedings Inst.C.E., vol. clxix, p. 126.

Ordinates of the b.h.p. line are, $y_B = 76 \cdot 6\ (x - 0 \cdot 67)$.

Ordinates of the i.h.p. line are, $y_I = 76 \cdot 6x$.

Mechanical efficiency $= \frac{(x - 0 \cdot 67)}{x}$, where x is the gas used per minute. The maximum efficiency at 200 revolutions per minute is $0 \cdot 79$.

The thermal efficiency of the engine may be expressed by the ratio of the ordinates which give the horse-power and the total heat supplied; this is taken by the line from G to G′, whose equation is $y_H = 316\ x$.

Thermal efficiency $= \frac{y_I}{y_H} = \frac{76 \cdot 6}{316} = 0 \cdot 242$

Ideal efficiency $= \eta = 1 - (\frac{1}{4})^{0 \cdot 4} = 0 \cdot 426$

Ratio of actual to ideal efficiency, $\frac{\eta'}{\eta} = \frac{0 \cdot 242}{0 \cdot 426} = 0 \cdot 568$

Thermal efficiency as a ratio of b.h.p. to heat supplied is $\frac{y_B}{y_H} = \frac{0 \cdot 242\ (x - 0 \cdot 67)}{x}$. The maximum efficiency at 200 revolutions per minute is $= 0 \cdot 19$.

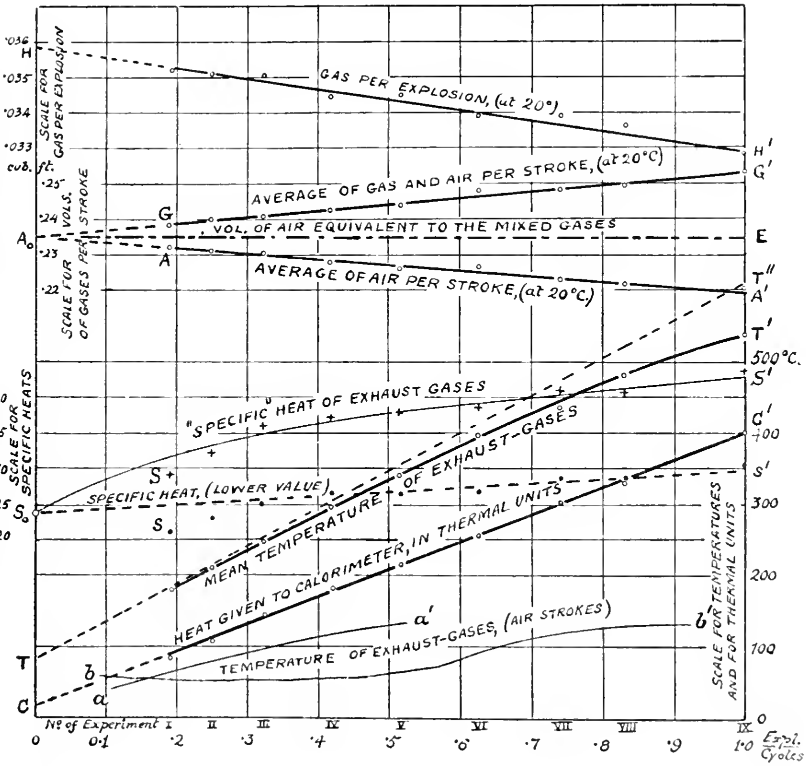
At full load the heat distribution is:—Exhaust $40 \cdot 1$ per cent., jacket $35 \cdot 7$ per cent. (including about 1 per cent. for radiation), indicated horse-power $24 \cdot 2$ per cent.

Mean Temperature of the Exhaust-Gases.—After making several experiments with thermo-couples and exhaust calorimeters, the author adopted the exhaust calorimeter described on page 116. In the design of this calorimeter special care was taken that the water should circulate around the exhaust-pipe, close up to the exhaust-valve, and that the cooling-surface was sufficient to enable the temperature of the outlet gases to be very nearly that of the inlet gases of the engine. For the mean temperature measurements which are given in Fig. 4 (page 123), the platinum couple was shielded by a porcelain tube, and arranged so as to be as close as possible to the exhaust-valve. Great care was taken in the calibration and readings of the pyrometers. The effect of the porcelain tube was to damp the response of the galvanometer so as to give mean temperature readings; the fluctuations of the

galvanometer due to extremes of temperature, whilst very apparent at light loads, almost disappeared at full load.

The mean temperature of the exhaust-gases (t_m) is given in Table 1, column 6 (page 118), and plotted on a base line of explosions to cycles, curve TT′, Fig. 4. It will be noticed that the inclination

FIG. 4.—*Mean Temperature of Exhaust-Gases.*



of the curve TT′ to the base line decreases at the higher loads. This decrease may be due to: (1) The decrease in the gas used per explosion at the higher loads. (2) An increase in the specific heat of the mixed gases at high temperature. (3) Other causes, one of which is the more rapid loss of heat, to the part of the calorimeter close to the exhaust, at high temperature.

Quantities of Gas and Air used per Stroke at Constant Speed.—Careful measurements show that whilst the average volume of mixed gases used per cycle at constant speed increases as the load increases, the average volume of air per stroke diminishes. This is shown in Fig. 4, where the dot and dash line A_0E gives the equivalent volume of air per stroke; this is constant at all loads at constant speed. The line HH′ shows that the gas used per explosion decreases as the load increases, hence the actual temperature of the gas leaving the cylinder, during the exhaust period which follows an explosion, will be less at high loads than at low loads; the lower mean temperature of the gases at low loads being due to the increased volume of gases which is then discharged into the exhaust during the dead strokes. It will be seen from Fig. 4 that the line giving the mean temperature of the exhaust-gases TT′ is less inclined at high loads than at low loads; on the assumption that the gas per explosion is the same at high loads as at low, calculations give the dotted line TT″ as the mean temperature.

Mean Specific Heat of the Exhaust Gases.*—From the mean temperature of the gases which pass the exhaust-valve, and the heat given to the calorimeter, the mean "specific" heat of the exhaust-gases has been calculated. S_0S', Fig. 4, represents the changes in the "specific" heat when the latent heat of the water vapour is not allowed for. S_0s' shows the result when allowance is made for the latent heat. Neither of the curves obtained is quite regular; in both curves the results from Tests 1 and 2 seem to be abnormally low, and as the specific heat given by the lower curve is less than that of air for the first two tests, a straight line has been drawn from 0·24 (specific heat of air at ordinary temperatures) on the axis; this line has been taken to represent the mean values of the lower curve: a fair curve has been drawn through the points on the

* The term mean "specific" heat as used in the following pages refers to the quantity of heat given to the exhaust calorimeter per pound of exhaust gases; in some cases, as will appear from the context, it includes the latent heat of the steam contained in the exhaust-gases.

curve SS′; this curve is obtained by calculations from the mean line of temperature TT′, and the mean line of heat to the calorimeter, CC′. The specific heat of superheated water vapour has been taken from 0·48 at 100° to 0·50 at 600°, and the latent heat of steam as 537, in centigrade units.

Whilst the mean temperature of the exhaust-gases as recorded and plotted may be too high at a low ratio of explosions to cycles, it is believed that the record is fairly reliable at high temperatures. As the result of many experiments on the mean temperature of the exhaust, for the proportion of gas used, the temperature during an exhaust explosion stroke lies between 520° C. and 550° C. (970° F. and 1020° F.). The temperature will depend upon the proportion of gas to air, amongst other causes, as well as upon the temperature of the jacket-water.

Temperature of the Exhaust Gases (Air Strokes).—If the temperature of the exhaust-gases (explosion strokes) is known, the approximate temperature of the exhaust-gases during the air-strokes (or "dead" strokes) may be found by assuming that the heat contained in the residual hot gases in the cylinder is taken up by the known quantity of cold air which enters the cylinder during the suction strokes. The calculations give approximate results only, as the specific heat can only be approximate; the piston and other parts in contact with the gases may either give heat to or take heat from the gases in contact with them.

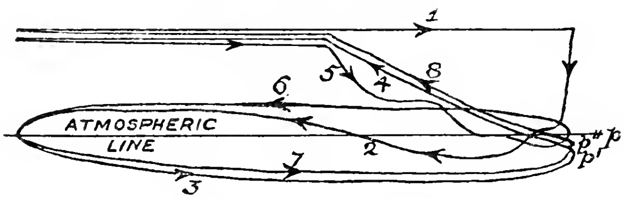
Two methods of calculation were adopted, one of which gives the curve *aa′*, the other gives the curve *bb′*, Fig. 4. The results indicate that the gases in the cylinder lose heat to the cylinder during the exhaust-strokes at high percentage of explosions, and take heat from the cylinder during the pumping strokes at low percentage of explosions.

Increase in the total volume of Gas and Air as the Load increases.—At constant speed of working, the total volume of gas and air increases with the total gas used, and with the number of explosions per minute. This increase, whilst partly due to the increased effective area of the apertures which open into the port

during the gas suction strokes, is mainly because the rate of flow of gases through an opening increases as the density of the gases decreases. The well-known law of the flow of gases through orifices, when applied to these experiments, gives numerical results which agree with the experimental numbers.

That the total volume of gas and air increases, during uniform mean-speed trials, at a high ratio of explosions to cycles, may also be shown by means of a light-spring indicator diagram. Fig. 5 shows the usual cycle of operations obtained from such a diagram, modified to prevent overlapping of lines at the top, in which the order of the curves is :—(1) Expansion after explosion. (2) Exhaust after explosion. (3) Inlet after explosion (no gas). (4) Compression

FIG. 5.—*Cycle of Operations.*



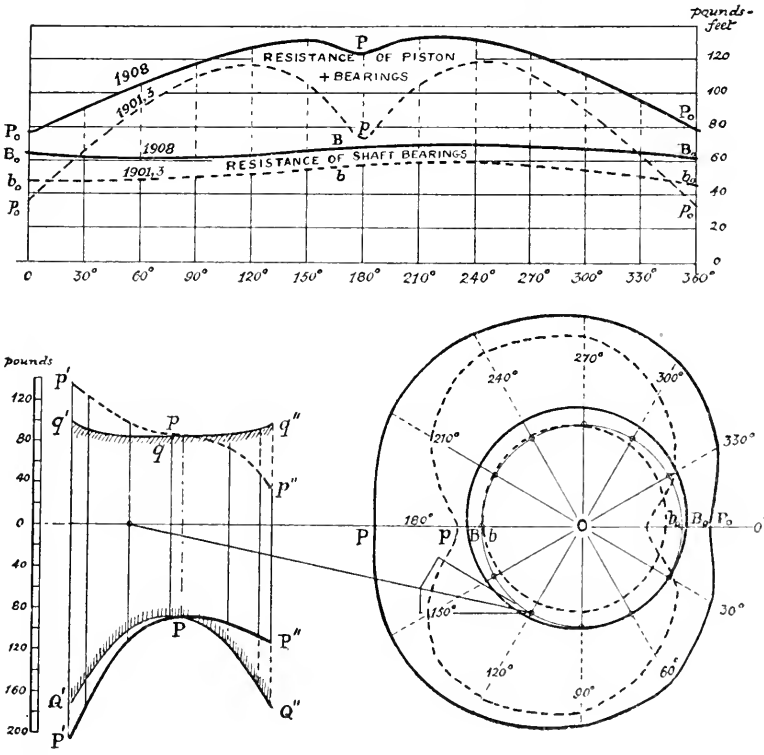
of dead charge. (5) Expansion of dead charge. (6) Exhaust of dead charge. (7) Inlet of gas and air. (8) Compression of the charge.

From the diagram it is seen that the pressures during both the exhaust- and suction-strokes after an explosion are lower than the pressures after non-explosion strokes. When both gas and air are admitted, the diagram shows that the line 8 crosses the atmospheric line farther to the right in the figure, or that the volume of the gases is greater when both gas and air are admitted; thus the diagram confirms the measurements given by the meters.

Experiments on Static Friction.—These experiments consisted in the determination of the torque necessary to develop motion in the rotating parts of the engine. The torque was found in each case by means of weights which were hung over the rim of the fly-wheel. Two separate sets of experiments were made :—(*a*) When the crank-

pin was free from the connecting-rod; (*b*) When the friction of the piston and connecting-rod bearings were included. The experiments were repeated after an interval of seven years; meanwhile a new brake-wheel had been put on the shaft and other alterations made, the total weight being increased from 2,350 to 2,850 lb.

FIG. 6.—*Experiments on Static Friction.*



In Fig. 6 the torques, in pounds-feet, have been plotted on a linear base and also as a polar diagram in which the moments are measured from the centre O. In both diagrams the broken lines represent the experiments made in 1901 and the full lines those of 1908. The ordinates of the lines B_0BB_0, and $b_0bb'_0$, give the torques

for the shaft when the crank-pin is free, whilst the ordinates of P_oPP_o, and p_opp_o, give the torques when the piston is connected to the crank-pin. The difference between P_oPP_o and B_oBB_o gives, for each angle, the torque required to overcome the friction of the piston and of the bearings at the ends of the connecting-rod.

From the polar diagram, the equivalent resistances offered by the piston at any part of the stroke have been obtained by a graphical construction. For the purposes of comparison the upper half of the 1901 diagram has been drawn, measured above the centre line of the stroke; and the lower half of the 1908 diagram, measured below the centre line of the stroke.

The curves $p'pp''$ and $P'PP''$, showing the apparent variation in resistance from end to end of the stroke of the piston, have been corrected for the turning moment, caused by the weight of the connecting-rod acting on the crank-pin, with the result that, in the 1901 experiments, the friction of the piston is nearly constant, as shown by the hatched line $q'qq''$; there is, however, a tendency for the frictional resistance to increase near the ends of the stroke. This increase of resistance near the ends becomes very remarkable in the 1908 experiments, as is shown by the corrected resistance line $Q'PQ''$. The friction near the middle of the stroke is nearly the same in both sets of experiments.

There was a considerable increase in the coefficient of static friction from 1901 to 1908, the mean value of the coefficient for the bearings being 0·175 in 1901 and 0·22 in 1908. The chief points of interest are, however, the curious change in the friction of the piston, and the experiments showing the difference between the so-called "static" friction and "kinetic" friction.

Experiments on Friction by Retardation methods.—It is interesting to compare the effects of "static" friction with the friction of motion. After the earlier sets of experiments had been made, some simple experiments on the retardation of the rotating parts demonstrated the well-known fact that the coefficient of "kinetic" friction is much less than the coefficient of "static" friction. The experiments showed also that the coefficient was greater than is

given by Tower's experiments. The conditions are different from the ideal conditions of Beauchamp Tower's experiments. In the gas-engine the cap brasses, while not tightly pressed on the journals, were sufficiently close to increase the resistance; in this way there was the added resistance due to the oil film between the top brass and the journal, whereas in Tower's experiments there was, as a rule, no resistance due to a cap.

The retardation method for the determination of the frictional resistances of the rotating and reciprocating parts of an engine has been successfully applied by Mr. Burnand* to the gas-engine. Following the method suggested by Mr. Burnand, and with his assistance in the experimental work, several retardation tests were made in connexion with the experiments of 1908.

In these experiments, not only was the method applied to friction load tests, but it was extended to include the retardation of the engine when running under the action of loads applied by the brake. The readings of the revolutions were taken from the revolutions counter in the usual way, and a record was obtained of the revolutions on a tape recorder, designed by the author.†

When the results of a retardation test are plotted with time from rest T, and revolutions from rest R, as ordinates, a "space" time-curve is obtained which can be very closely represented by an expression of the form: $R' = C(T')^n$, where $T' = T + a$, and $R' = R + b$, where a, b and C are constants. From this expression the number of revolutions per minute N, and the acceleration in revolutions per minute, per minute A, are obtained by differentiation.

Although the difference between the "space" time-curves obtained from the equations and that obtained from the experiments are very small, the values of N and A from the plotted differentiation are more accurate than the values from the equations; hence the diagrams given are from the plotted differentiations.

These experiments on the friction of motion had, for their object, the investigation of the relative distribution of friction due

* *Engineering*, 13 July, 1906, pp. 30, 31.

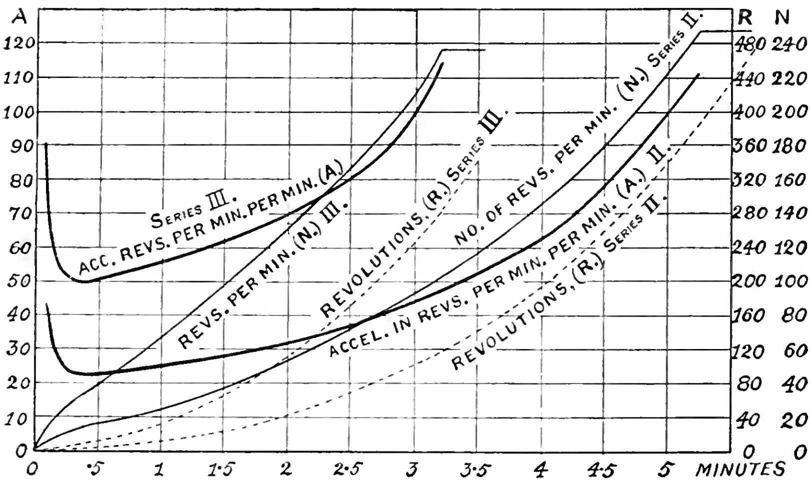
† *Engineering*, 3 Nov. 1911.

to the resistances of separate parts at different speeds. Various methods of working and plotting were tried; it was finally decided that, for the purposes of comparison, it would be convenient to plot the results as if the engine were starting from rest; hence, whilst the experiments are on retardation, the plotting is on the assumption of their being accelerative in character.

There were in all nine series of tests. Series I: Rotating parts only, the connecting-rod being disconnected; Series II: Piston, etc., connected as in working, but the exhaust-valve is kept open;

FIG. 7.—*Retardation Tests.*

Series II. Exhaust-Valve Open. Series III. Exhaust-Valve Working.

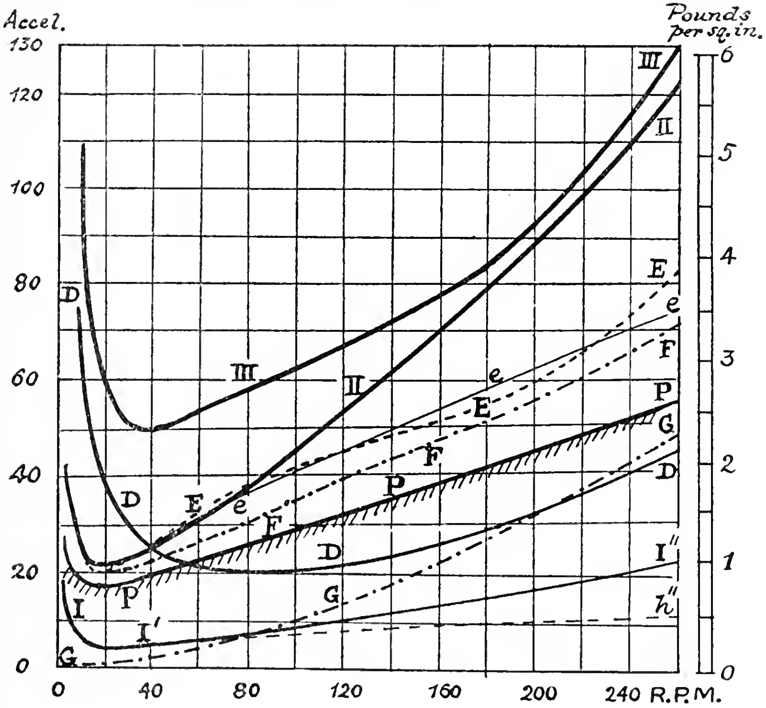


Series III: Exhaust-valve working, and the compression of gases is as in ordinary working without load; Series IV to IX: as in Series III, but in each one of the series there was a constant load on the brake-wheel, the resisting load increasing from IV to IX. The brake, which surrounded the wheel, was loaded on one end with a dead load; and on the other end, vertically opposite, there was a spring balance, the same arrangement as was used for determinations of the brake horse-power.

The method of plotting the results is illustrated in Fig. 7, which deals with Series II and III only. On a base line of time

in minutes, the number of revolutions run from rest is given by the dotted line R. From this curve, by careful differentiation, the number of revolutions run per minute is determined and shown by the curve N. Again, by differentiation, the acceleration in revolutions per minute, per minute, is obtained, as shown by the curve A.

FIG. 8.—*Combination of Results of Retardation and other Friction Tests.*



In Fig. 8 the acceleration curves are drawn on a base line of revolutions per minute; the scale of the acceleration is given on the left-hand side in revolutions per minute, per minute, and on the right-hand side in pounds per square inch of piston area. The curve I I′ I″ is from Series I: rotating parts only. The curve II II is from a test with friction load only, the exhaust-valve being

kept open. The curve III III is from a similar test with the exhaust-valve working.

From these curves the relative resistances in pounds per square inch of piston area may be scaled off. In the same way, diagrams have been prepared showing the effect of a load on the brake-wheel. In these tests, after the engine had been running for some time with a load on the brake-wheel, the gas was shut off and the engine allowed to come to rest under the action of the load on the brake, the valves being allowed to work as in the ordinary running of the engine. As the general method is the same as in the tests under friction load only, one example will serve to illustrate the results obtained.

Series VI, Net Load on the Brake-Wheel, 95 *lb.*—The counter registered 106 revolutions from the time the gas was shut off to the time of stopping, a period of 0·92 minute.

In the Table 2, the time from rest is taken in tenths of a minute, comparative values are given from formulæ and from plotted results.

TABLE 2.

T	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
R	1·5	5	11	19·3	31	44	61	79	101
N (curve)	24	48	72	97	123	150	176	203	230
N′	24·46	47·64	71·94	97	122·7	148·9	176	202·6	229·7
A (curve)	240	242	246	256	260	264	272	280	290
A′	220	239	248	255	260	265	269	272	276

The values N′ and A′ are from the empirical formulæ:—

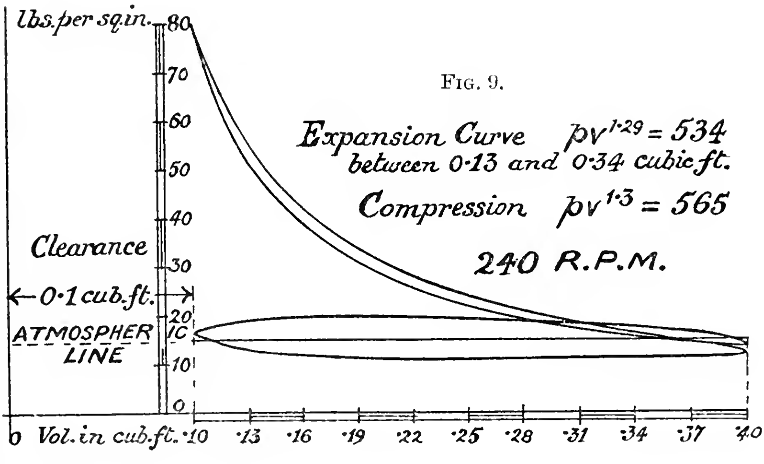
$$R' = 120\,(T + 0\cdot02)^{2\cdot1};\quad N' = 252\,(T + 0\cdot02)^{1\cdot1};$$
$$A' = 278\,(T + 0\cdot02)^{0\cdot1}.$$

With very nearly a full load on the brake-wheel, the total resistances almost mask the gradually increasing effect of the

frictional resistances. There is, however, a distinct increase in the total resistances, as is shown by the values of A in the Table—an increase from 240 at 24 revolutions per minute to 290 at 230 revolutions per minute.

Before dealing with the methods adopted for the determination of the separate effects of friction, attention is drawn to the shape of the curves I, II, and III in Fig. 8. These curves show that at a low velocity the friction is very considerably augmented—that is, when the shaft is about to come to rest. If the results are compared with those obtained when the wheel is started from rest

Fig. 9.



by forces applied tangentially, it can be shown that there is an almost sudden drop from A = 100 to A = 4, in the curve I I′I″, and a corresponding drop from A = 175 to A = 20 when the friction of the piston is included, and to A = 50 when the compression is also included; *see* curves II and III.

Frictional losses deduced from Indicator Diagrams.—Several series of tests were made in order to ascertain, by means of indicator diagrams, the loss of work in the gas-engine. The object of the experiments was to determine: (1) The work done in the cylinder

during the compression and subsequent expansion strokes; (2) The work done during the exhaust and suction strokes. Two methods of experimenting were adopted:—

(*a*) The engine was run at a steady high speed for some time on friction load only, until the conditions of working were steady; the gas was then shut off and the engine allowed to come to rest. During the time the engine was slowing down, the indicator diagrams were taken at regular intervals; the speed of the engine, at the instant the diagrams were taken, being found from the retardation curve.

(*b*) The engine was run at various steady speeds, and the indicator diagrams were taken under ordinary conditions of friction load only.

1. *Compression and Expansion Tests.*—The general character of the diagrams obtained during compression and expansion is shown by the upper loop of Fig. 9. The area of the loop increases as the speed of the engine decreases; the change of mean pressure with change of speed is shown by the curve AA′, Fig. 10, in which the mean pressures, given in the Table, are plotted as ordinates, the abscissæ being revolutions per minute.

Diagrams No. . .	1	2	3	4	5	6	7
Revs. per min. N. .	245	155	92	73	57	32·5	15 to 10
Mean pressure p_m. .	1·5	1·9	2·3	2·75	3·4	4·4	11·6

The curve which is drawn through the experimental points represents the equation $p_m N^{\frac{2}{3}} = 50$, where p_m is the mean pressure found from the diagram, in pounds per square inch.

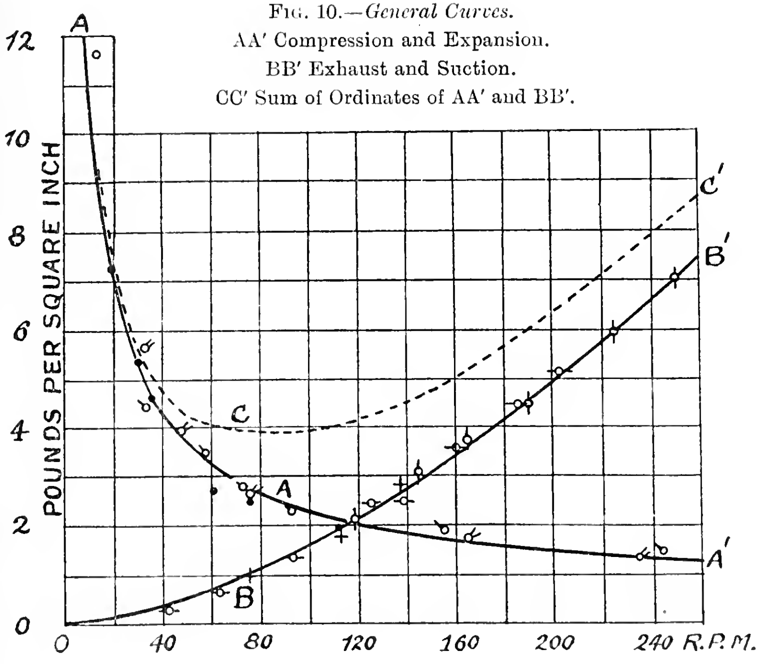
2. *Suction and Exhaust Tests.*—The indicator diagrams, of which an illustration is given in the lower loop of Fig. 9, were taken by means of an indicator fitted with a low-pressure spring. The loops taken at high velocity were quite separate and distinct on the indicator cards, whilst the low velocity loops tended to overlap as they approached the atmospheric line.

The diagrams were taken during the time the engine was coming to rest. N was determined from the retardation curve.

Diagram No. . .	1	2	3	4	5	6	7	8	9
Revs. per min. N. .	252	225	190	165	145	118	92	65	43
Mean pressure p_m. .	6·97	5·85	4·47	3·74	3·10	2·07	1·26	0·61	0·22

Total pressure on the piston in pounds = Area × mean pressure = $35p_m$.

FIG. 10.—*General Curves.*
AA′ Compression and Expansion.
BB′ Exhaust and Suction.
CC′ Sum of Ordinates of AA′ and BB′.



In Fig. 10 the mean pressure at various speeds is plotted on a base line of revolutions per minute; a line OB drawn through the points corresponds approximately to a formula $p_m N^n = C$. The logarithmic plottings of the experiments gave values of n varying

from $1 \cdot 86$ to $1 \cdot 6$, one of the formulæ obtained being $p_m = 0 \cdot 001 N^{1 \cdot 6}$ (Curve OBB′).

The mean-pressure increases with increase of speed; the loss of pressure during the suction-stroke is due to the restricted air-inlet past the valve, and to the frictional losses in the inlet pipe; to this must be added the frictional losses in the air-meter, which was connected during the experiments. The gain in pressure during the exhaust-stroke is due to similar causes acting on the exhaust side. The combined effect of the curves AA′ and BB′ is shown by the dotted curve CC′, in which the ordinates are the sums of the ordinates of AA′ and BB′.

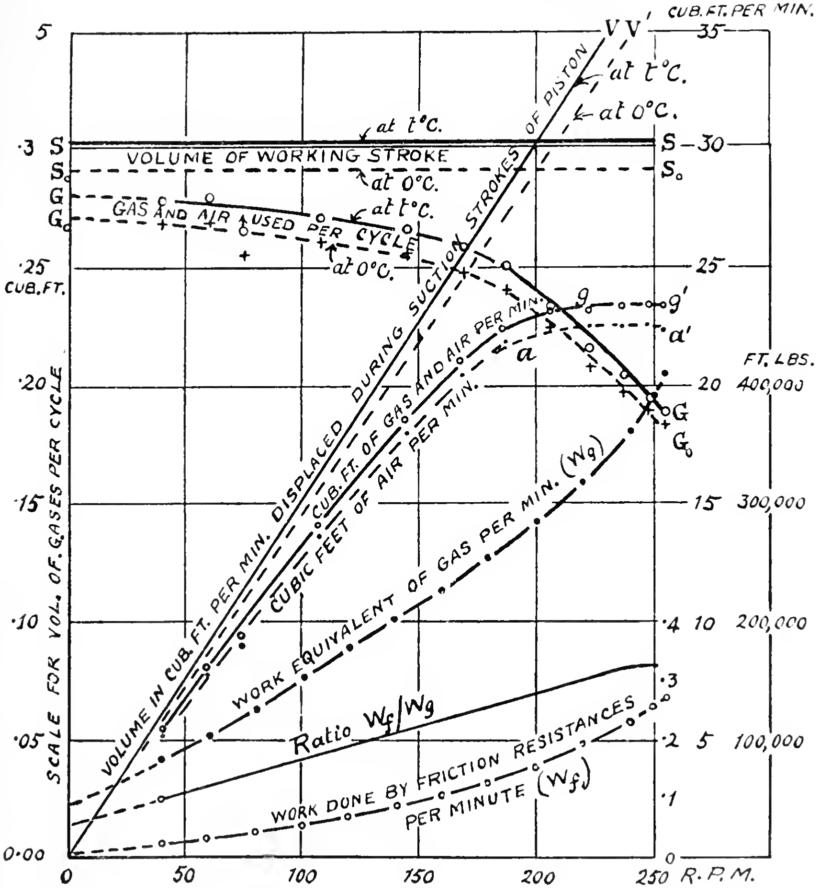
Progressive Speed Tests under Friction Loads.—The object of the experiments was to determine the variation in the quantity of gas used with the variation in speed, and from this the frictional resistances.

The series commenced with the tests at the highest safe speeds of the engine; the governor, which normally is controlled by a combination of a spiral spring and weighted cone, was used in these tests without its spring, the load for the highest speeds being made up of weights; for the lowest speeds, the effect of the weight of the governor itself was diminished by using a light spring which acted on the striker arm in opposition to the governor. In this way it was possible to obtain a range of speed from 254 to 40 revolutions per minute.

Table 3 (page 138) gives the results when the temperatures of the gas and air are reduced to 0° C. These results are plotted in Fig. 11, in which the base line is revolutions per minute. There are two curves which represent gas and air per cycle, the lower curve G_0G_0 being taken from the Table, where the quantities are reduced to volumes at 0° C.; the upper curve GG is from the volumes recorded at the temperature of the tests. The upper curve may be compared with the straight line SS, representing the volume of the working stroke, which is $0 \cdot 3024$ cubic foot. The air-valve commences to open before the beginning of the suction-stroke, and does not completely close until after the end of the suction-stroke, but the

period of the opening of the air-valve permits of a maximum of only 0·281 cubic foot of air entering the cylinder per suction-stroke; this corresponds to 93 per cent. of the volume of stroke.

FIG. 11—*Progressive Speed Tests (Friction Load).*



As the speed increases, the volume of mixed gases admitted per cycle becomes gradually less, until at 200 revolutions per minute, the ordinary speed of the engine, the total of mixed gases is about

TABLE 3.—*Progressive Speed Tests under Friction Load.*

Each test ran for 10 minutes, after constant conditions were established. Gas and Air corrected at 0° C. Barometer at 30 inches. Pressures of Gas, 2·5 inches of Water.

No. of Test.	Revolutions per minute.	Explosions per minute.	Gas per minute (Net).	Air per minute.	Gas and Air per minute.	Gas and Air per cycle.	Temperature of Outlet from Jacket.
			cubic feet.	cubic feet.	cubic feet.		°C.
I	254·0	31·2	0·930	22·35	23·28	0·183	44·0
II	217·6	29·0	0·845	22·60	23·45	0·190	41·0
III	236·5	25·8	0·797	22·50	23·30	0·197	41·6
IV	222·1	22·3	0·715	22·40	23·12	0·208	41·6
V	205·7	19·5	0·671	22·20	22·87	0·223	42·7
VI	186·0	16·7	0·600	21·80	22·40	0·241	43·0
VII	168·2	14·1	0·529	20·40	20·93	0·249	42·8
VIII	144·6	11·5	0·446	18·05	18·50	0·256	42·1
IX	106·9	8·6	0·355	13·53	13·89	0·260	41·0
X	73·6	9·3	0·348	8·95	9·30	0·254	58·0
XI	58·8	7·0	0·219	7·64	7·90	0·269	36·0
XII	40·3	4·4	0·184	5·16	5·35	0·267	—

79 per cent. of the volume of stroke, whilst at 250 revolutions per minute 64 per cent. only is admitted. The volume of mixed gases admitted will depend upon the temperature of the jacket; at high temperatures of circulating water the volume of gases admitted per suction-stroke is less than at low temperatures. It is probably in consequence of this that the power falls off when the jacket is allowed to reach a high temperature.

The decrease in the volume of air and gas at high speeds is also shown by the curves Oaa' and Ogg', which give the volume of air, and of air and gas respectively, in cubic feet per minute. These curves may be compared with the straight line OV, which gives the volume swept out by the piston during the suction strokes; or, since the lower curves Oaa' and Ogg' have been corrected for temperature and reduced to 0° C., the comparison is better made with the line OV′, which is calculated so as to allow for the gas and air being at 0° C. instead of at 10° C., the temperature of the experiments.

A comparison may be made between the gas used for the friction load at any particular speed and the retardation due to frictional resistances at that speed. The calorific power of the coal-gas, taken when the progressive speed tests were made, was 310 Centigrade Pound Thermal Units, or 432,000 foot-pounds per cubic foot of gas, taken at the higher value. The work equivalent of the gas is $W_g = 432{,}000\ G$ foot-pounds per minute, where G is the gas used per minute in cubic feet. From the retardation tests made under friction load only, with all the valves in operation, the work equivalent of the frictional resistance is $W_f = 4 \cdot 11\ AN$, foot-pounds per minute. A is acceleration, *see* next page.

The values of W_f and W_g and of the ratio of W_f to W are plotted in Fig. 11. The value of $\frac{W_f}{W_g}$ increases regularly from $0 \cdot 108$ to $0 \cdot 327$ between 40 and 240 revolutions per minute where it is a maximum.

Loss of Energy during Retardation.—The following constants were obtained from the rotating parts of the engine by careful measurements and calculations;—

Weight of rotating parts, exclusive of cam-shaft, W = 2,850 lb.

Moment of inertia, 376 (foot^2 unit).

Kinetic energy, $2 \cdot 05\ N^2$.

The constant pressure, in pounds per square inch of piston area, acting during the whole of each stroke, $p = 0 \cdot 047$ A

A is the acceleration in revolutions per minute, per minute.

Work done in the cylinder per stroke $= 43 \cdot 6\ p$ foot-pounds.

Continuous torque on the shaft, $T = 0 \cdot 653$ A (pounds, feet, units).

Friction of Journals.—From the curve I I′ h'', in Fig. 8 (page 131), for the retardation when the rotating parts are free from the connecting-rod, the coefficient of friction is: $\mu = \frac{T}{Wr} = 0 \cdot 0022$ A.

r is the radius of the shaft bearing, $\frac{1 \cdot 25}{12}$ feet.

At $N = 20$, $A = 3 \cdot 8$, $\mu = 0 \cdot 008$ (the minimum value).

$N = 40$, $A = 5$, $\mu = 0 \cdot 011$. $N = 120$, $A = 10$, $\mu = 0 \cdot 022$.

Combination of Results of Retardation and other Friction Tests.—Fig. 8 has been drawn to show the relation between the resistances deduced from the retardation of the rotating parts, and the resistances deduced from the suction and compression loops of the indicator diagrams. The curve III is obtained when the exhaust valve is in operation. The curve DD is from the curve CC′ in Fig. 10. From the formula $p = 0 \cdot 047$ A, we obtain $p' = 0 \cdot 188$ A, where p' is the pressure during one stroke out of four, as is the case in the suction and compression curves, hence $A = 5 \cdot 32\ p'$. If the ordinates of CC′ in Fig. 10 are multiplied by $5 \cdot 32$, the ordinates of DD in Fig. 8 are obtained. Hence the curve DD represents the retardation equivalent of the pressures obtained from the suction and compression loops of the indicator diagrams. The difference between the ordinates of III and DD gives the curve EE. This curve represents the resistance due to the friction of the piston and of all the bearings in connexion with the reciprocating and rotating parts.

The curve II is the retardation curve when the exhaust-valve is kept open, hence the resistance equivalent to the compression and

expansion loop of the indicator diagram is absent, that is, of the curve AA′ in Fig. 10; on the other hand, there will be a resistance due to the expansion and compression portions of the cycle, due to the air being drawn in past the exhaust-valve and again exhausted; added to this is the resistance due to the same causes acting during the ordinary suction and exhaust strokes, both the air-valve and the exhaust-valve being open during the suction stroke.

The curve GG, Fig. 8, is drawn on the assumption that the average resistance during a complete cycle varies as the resistance due to the suction and exhaust loop only, that is, as the curve BB′ in Fig. 10. The difference of the ordinates between II, Fig. 8, and GG gives the line FF.

Thus by two methods of working we have the curves EEE and FFF; the ordinates of either give the retardation due to the piston friction together with the friction of the bearings and the external air resistances. EE and FF do not coincide; they are sufficiently close to act as checks on one another. The curve I I′I″ represents the resistance of the rotating parts together with the external air resistances. The differences between the ordinates of EEE and I I′I″ give a curve from which the fair curve PPP is drawn; this represents the resistances due to the friction of the piston and connecting-rod bearings.

It was not possible to carry the experiments on the retardation of the crank-shaft, free from the piston, to speeds higher than 35 revolutions per minute. The curve I I′ is experimental; it has been continued to *h*″ to represent the friction of the bearings, and to I″ to represent the friction of the bearings together with the resistance offered by the air to the motion of the fly-wheel and other rotating parts.

Several diagrams similar to Fig. 8 (page 131) have been drawn from various retardation tests. The retardations at different speeds, as represented by the line III, do not always give the same line; various causes, one of them being imperfect lubrication, interfere with the results. The temperature of the jacket-water seems to have a marked effect on the resistance; it was observed that an increase

in resistance accompanied an increase in the temperature of the jacket-water.

The friction of the connecting-rod bearings at the crank-pin and piston gudgeon, although not negligible, is relatively not very important; if allowances are made for the piston resistances and the weight of the connecting-rod, it is probable that the friction of the piston as given above is within 10 per cent. of its true value.

The "static" friction of the piston, as shown by the curve Q′PQ″, Fig. 6 (page 127), is equivalent to 5 lb. per square inch of piston area at the ends of the stroke, falling to 2·5 lb. near the middle; 3·5 lb. is an average value. The "kinetic" friction, as shown by PPP, Fig. 8 (page 131), falls to 0·75 lb. per square inch at 20 revolutions per minute, and then increases regularly to 2·5 lb. as the speed increases to 240 revolutions per minute.

The Paper is illustrated by 11 Figs. in the letterpress.

The Institution of Mechanical Engineers.

ANNUAL GENERAL MEETING.

FEBRUARY 1915.

The SIXTY-EIGHTH ANNUAL GENERAL MEETING was held at the Institution on Friday, 19th February 1915, at Eight o'clock p.m.; MICHAEL LONGRIDGE, Esq., Vice-President, in the Chair.

The CHAIRMAN, in opening the Proceedings, said he desired to read the following extract from a letter he had received that morning from Sir Frederick Donaldson, the President: "I am more than disappointed to find that influenza still maintains its hold upon me, and that it will certainly now be impossible for me to go to London for to-morrow's Meeting. I shall therefore be most grateful if you will express my keen personal regret to the Members of the Institution for my inability to fulfil the special duty of my office as President in handing it over to Dr. Unwin, my successor. I shall also be glad if you will express to Dr. Unwin how much I wish I could have done my duty on this occasion, and ask him to condone my absence."

The Minutes of the previous Meeting were read and confirmed.

The CHAIRMAN announced that the following Transference had been made by the Council:—

Associate Member to Member.

CHISHOLM, JOHN, ... Airdrie.

The Annual Report of the Council for the year 1914 was then presented.

The CHAIRMAN said the next business was the motion for the adoption of the Annual Report. As all the members had received the Report, and no doubt studied it, he would only refer briefly to some of the more important matters mentioned in it. The first was the roll of the Institution. This again showed an increase in the membership, which, though smaller than usual, was not unsatisfactory considering all that had happened since the middle of last year. Since the last Annual Meeting fifty-eight members had been lost by death, among whom were Mr. Edward B. Ellington, who was President of the Institution in 1911 and 1912; Engineer Lieut.-Commander Venning, Associate Member, who went down in H.M.S. "Pathfinder"; Lieut. H. Schneider, Associate Member, and Mr. R. D. McGroarty, Mr. R. M. C. McNaughton, and Lieut. H. I. Vandell, Graduates, whose names were written in the Roll of Honour of the War.

The Accounts of the Institution during the past year showed a considerable falling off in the balance of revenue over expenditure, nevertheless the Institution was still nearly £1,000 to the good on the year's working.

He desired to refer next to the Benevolent Fund, which had now been started for a year and a half; the Fund had not increased to the extent the Council had hoped. The amount standing to its credit at the present time was only £5,467, and the annual subscriptions were only £251. Considering that there were 5,732 Members and Associate Members of the Institution, besides Graduates, he thought a good deal more ought to be done. If they could only realize the situation of those who by misfortune, illness, or death were left to face the world without resources, he was certain that more would be done. He did not press for donations to capital, though they would be welcome, because comparatively few members had capital to give; but he did press for annual subscriptions to the Fund. There were few members who could not give something, however little, every year. Small sums mounted up when many gave. A subscription of only 10*s.* from every Member and Associate Member would give the Committee nearly £3,000 a year. That and more, he feared, would be needed

in the near future, and he earnestly hoped the Committee would not be left to meet a great necessity with the miserable income now available.

Fifty-five candidates presented themselves for the Institution Examinations, of whom forty-eight passed, some exceedingly well, with a very high percentage of marks. He thought that was very satisfactory.

One of the most important works connected with the Institution was research, and there were now many Committees at work dealing with various subjects.

Considerable progress had been made by the Alloys Research Committee, which had been continuing its work at the National Physical Laboratory, and it was expected that the Eleventh Report would be ready for publication during the present year.

The results of the research under the direction of Professor Arnold and Professor Read were presented for discussion at the March Meeting in the form of a Paper entitled: "The Chemical and Mechanical Relations of Iron, Tungsten, and Carbon, and of Iron, Nickel, and Carbon."

The Refrigeration Research Committee, under the Chairmanship of Sir J. Alfred Ewing, had met on several occasions during the year, and their first Report was presented and discussed at the October Meeting, and the Committee had been authorized by the Council to carry out experiments with the object of supplying data which were not now available regarding the physical properties of the substances used in refrigeration.

The Wire Ropes Research Committee appointed in 1913 had held three Meetings under the Chairmanship of Mr. Walter Pitt, and had addressed a number of questions concerning the life history of wire ropes to various large users, and as a result had received over 200 life histories for consideration.

A Research Committee, of which Captain Sankey was Chairman, had been appointed to report what experiments relating to "The Action of Steam passing through Nozzles and Steam-Turbines" could be undertaken with advantage. Abstracts of almost everything that had been written on the subject had been made and

(The Chairman.)

considered, and the Committee, having reported that further experiments were desirable, had been re-appointed to carry out some of these experiments.

Another Research Committee had been appointed to report upon a Hardness Test for Hardened Journals and Pins, of which Dr. Unwin was Chairman. Some tests had been made, and other experiments were under consideration.

A proposal to form what was called in the Report a "General Research Committee" was discussed in February at a Conference of the Council with representatives of the Universities, Scientific Societies, and large British engineering firms, and an Advisory Committee was appointed to prepare a scheme for the co-ordination of research. He might perhaps explain that this Committee was not, as its title might imply, a Committee for undertaking research; it was rather a Committee for co-ordinating and indexing researches which had been made, and were continually being made, by manufacturers and others, and for considering what other researches were needed to complete investigations already partly made.

With regard to the War, which occupied their thoughts so much at the present time, the members would remember that a proposal had been made that the Institutions of Civil, Mechanical, and Electrical Engineers should raise an infantry battalion; they also knew that that proposal had been abandoned in favour of the formation of an Engineer Unit of the new Royal Naval Division. That unit of 500 men was completed at the end of September, and a set of band instruments was presented to it by the Councils of the three Institutions. Later, an invitation was received from the War Office for the nomination of a number of members of the Institution for inclusion in a list of candidates for temporary Commissions in the Royal Garrison Artillery. Twenty-one candidates were selected by the Council, in conjunction with Major-General Ruck, and had been recommended for Commissions.

Shortly after the War began, the upper floor of the new wing of the Institution building was offered by the President for the use of the Prince of Wales's Fund. The drawing office and other rooms on the third floor had been taken by His Majesty's Office of Works

for the use of one of the War Office Committees, with the consent of the Council. Although there might be some inconvenience to the members, he was sure they were all glad to do whatever they could to help the Government in the present conditions, and that they would support the Council in the action that had been taken.

The past year had been marked by another departure from the ordinary routine. In June the first number of the Institution Journal appeared, and had been received by members up to the end of 1914 in addition to the volumes of "Proceedings." The issue of "Proceedings" in quarterly parts would now be discontinued, except to those members who signified their desire to receive them, in addition to the Journal.

In response to an application received from the Board of Education for assistance in the preparation of a Memorandum on the teaching of Engineering in evening Technical Schools, the Council appointed a representative Committee, who went into the matter in great detail. Their criticisms, opinions, and suggestions upon the draft Memorandum were communicated to the Board, together with an offer of a Conference if the Board thought it desirable. That, he thought, was a most important step, and it was very gratifying to find that at last the war between the theoretical and the practical man was near its end, and the two were beginning to discover that they could work together, to their mutual advantage.

An application had been received from the Board of Trade for observations upon a suggested amendment of the rule for ascertaining the Nominal Horse-Power of Marine Engines. He supposed the opinion of most of the members was that the term "nominal horse-power" ought to be abolished altogether. The opinion of the Council was the same; but knowing that the amended rule was to be used for fixing the number of engineers to be carried on board ships and similar rating purposes, they only told the Board that they did not consider a rule for Nominal Horse-Power of any value in an engineering sense.

The Summer Meeting of the Institution was held in Paris, and was a very pleasant one. A silver candelabra was presented to

(The Chairman.)

Mr. Hanning, President of the British Chamber of Commerce in Paris, as a souvenir of the Meeting. A like compliment would have been paid to M. Armand de Dax, the Secretary of the Société des Ingénieurs Civils de France, had he not requested that the money value of the intended gift should be handed to the British Red Cross Society. M. Sauvage, the author of one of the Papers read at the Meeting, went to the Front shortly after the Meeting, and had been there ever since, happily, so far as he knew, unharmed.

The Institution had been represented during the year on the Courts of several of the Universities, many Government Bodies, and Scientific and other Societies of the kind, which was another tie in the alliance between the practical and the theoretical man.

The Calcutta and District Section of the Institution had held several Meetings, and an Annual Dinner, which was attended by 135 members and guests.

He had much pleasure in asking the members to adopt the Report which had been presented by the Council.

The Motion for the adoption of the Report was then put, and was carried by acclamation.

The SECRETARY read the following list of the Medals and Prizes that had been awarded in connexion with the Papers read and Examinations held during the past year:—

"*Thomas Hawksley*" *Gold Medal* for the best Papers published in the Proceedings of 1913–14 respectively:
To ROBERT S. WHIPPLE, Professeur EDOUARD SAUVAGE, *Member*, and ANATOLE MALLET. (Proceedings 1915, pages 4–5.)

Water Arbitration Prize: To Professor A. H. GIBSON, D.Sc., *Member*. (Proceedings 1915, page 5.)

Institution Examinations: To J. H. ARMFIELD, W. M. HAMBLY, and H. GISSEL. (Proceedings 1915, page 6.)

Best Papers in the Graduates' Association: To W. J. DRUMMOND, *Graduate*, and RALPH JACKSON, *Graduate*. (Proceedings 1915, page 15.)

The Chairman reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council, and that the following were found to be duly elected :—

President.

W. Cawthorne Unwin, LL.D., F.R.S., . .	London.

Vice-Presidents.

William H. Allen, ...	Bedford.
J. Rossiter Hoyle, ...	Sheffield.

Members of Council.

Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S., .	London
John Dewrance, ...	London.
Sir J. Alfred Ewing, K.C.B., LL.D., F.R.S., .	London.
Henry A. Ivatt, ...	Hayward's Heath.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S., ...	London.
William H. Patchell, ...	London.

The Council for the present year is therefore as follows :—

President.

W. Cawthorne Unwin, LL.D., F.R.S., . .	London.

Past-Presidents.

John A. F. Aspinall, M.Eng., . . .	Manchester.
Sir H. Frederick Donaldson, K.C.B., . .	Woolwich.
Sir Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
William H. Maw, LL.D., ...	London.
E. Windsor Richards, ...	Caerleon.
Percy G. B. Westmacott, ...	Ascot.
J. Hartley Wicksteed, ...	Leeds.

Vice-Presidents.

William H. Allen, ...	Bedford.
Henry Davey, ...	Ewell.
Edward Hopkinson, D.Sc., ...	Manchester.
J. Rossiter Hoyle, ...	Sheffield.
Michael Longridge, ...	Manchester.
Mark H. Robinson, ...	London.

Members of Council.

Archibald Barr, D.Sc., ...	Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S.. .	London.
Dugald Clerk, D.Sc., F.R.S., . . .	London.
Sir A. Trevor Dawson, ...	London.
John Dewrance, ...	London.
Sir J. Alfred Ewing, K.C.B., LL.D., F.R.S., .	London.
Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S.,	London.
Charles Hawksley, ...	London.
H. S. Hele-Shaw, LL.D., D.Sc., F.R.S., .	London.
Alfred Herbert, ...	Coventry.
George Hughes, ...	Horwich.
Henry A. Ivatt, ...	Hayward's Heath.
Robert Matthews, ...	Manchester.
Donald B. Morison, ...	Hartlepool.
Sir Gerard A. Muntz, Bart., ...	Birmingham.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S., ...	London.
William H. Patchell, ...	London.
Walter Pitt, ...	Bath.
Captain H. Riall Sankey, R.E., ret., . .	London.
Wilson Worsdell, ...	Ascot.

(One Vacancy to be filled up in March.)

The Chairman said the period of the evening had now arrived at which it was usual for the retiring President to bid farewell to all his greatness and to install his successor in the Chair. However glad he might be to lay down the burden of the responsibility which every President of the Institution must assume, he thought that to close one of the best pages of his life, and to turn down the page practically for ever, must give rise to a certain amount of sadness and regret. Personally, although he occupied the President's place, he had no such feeling; he had the pleasure of welcoming Dr. Unwin to the high position to which the members had elected him without the pain of giving it up himself. He would like to have said a word about the late President, Sir Frederick Donaldson, but that duty had been placed in older and abler hands. He did not propose to say anything about Dr. Unwin. It would be unbecoming, and it was quite unnecessary. Most of those present had known Dr. Unwin's reputation since they were boys. He would now ask Dr. Unwin to take the Chair, nothing doubting (to paraphrase the words of an ancient ritual with which many of them were acquainted) that his conduct in the well ruling and governing of the Institution would be such as to merit the choice the members had made. He offered Dr. Unwin their hearty congratulations on the high office he had attained, and he thought the members might congratulate themselves on having a President whom they could honour and esteem, as they honoured and esteemed him whom Dr. Unwin now succeeded.

The Chair was then taken, amid hearty cheering, by the President, Dr. W. Cawthorne Unwin.

The President (Dr. W. Cawthorne Unwin) said his first duty was to thank the members for the honour they had done him in electing him as their President, and in doing so he could hardly express how deeply he felt such a mark of their goodwill and confidence. He took the Chair in times which were anxious and difficult, and all he could say was that he would do his best to serve the interests of their great Institution. He would not say more

(The President.)

at present, because at no very distant date he would have an opportunity of expressing himself more fully.

Dr. WILLIAM H. MAW (Past-President) said that, as the only Past-President present at the Meeting, it was his very pleasant privilege to propose that a most hearty vote of thanks be accorded to the retiring President, Sir Frederick Donaldson. It was a great disappointment, not only to Sir Frederick but to all the members, that it was impossible for the late President to receive in person the vote of thanks which they desired to accord to him. Sir Frederick's Presidency had been a most successful one. Although an exceedingly busy man, and very great demands were made upon his time, they had never been allowed to interfere in any way with the carrying out of the full duties of the Presidency of the Institution. It would be remembered that in the first year of Sir Frederick's Presidency the Summer Meeting of the Institution was held at Cambridge. The idea of holding the Summer Meeting at a University Town was an entire departure from previous practice, and in some quarters it was thought doubtful whether it would be a success. It was entirely Sir Frederick's idea that such a Meeting should be held, and, thanks to him, it proved to be a successful one in every way. Every one who took part in that Meeting possessed most pleasant recollections of the manner in which they were received at the University, and of the smoothness with which all the proceedings were carried out. It was arranged that the Summer Meeting for 1914 should be held in Paris, and for some months immediately preceding the Meeting Sir Frederick devoted an immense amount of time and attention to the organization of its details. Unfortunately, he was not able to attend that Meeting, as the shadow of the War was already upon the country, and it was necessary for him to devote himself to his duties at Woolwich Arsenal. In the absence of the President, Mr. Longridge conducted that Meeting in a most successful manner, but Dr. Maw was sure that it was a source of regret to Mr. Longridge that Sir Frederick could not witness personally the success of the Meeting.

During the last few months Sir Frederick had been working at very great pressure at Woolwich Arsenal in turning out munitions of war, and his work in that connexion deserved their utmost praise. Notwithstanding the fact that he had had to contend with labour difficulties, and had had to carry out an amount of work which was never anticipated a few months before the War began, he had not in any way limited the help he had rendered to the Institution. He had not been able to take charge at the Meetings, but all the members of the Council knew that he had never failed to give the most earnest attention to all matters of detail connected with the Institution, and to help his colleagues on the Council with most valuable advice on every possible occasion. He (Dr. Maw) did not think it was necessary for him to say more than that the members regarded Sir Frederick Donaldson's Presidency as most thoroughly successful in every way. He therefore formally proposed that a most hearty vote of thanks be accorded to him for his conduct in the Chair during the past two years, and also that there should be conveyed to him their most sincere wishes for his prompt and thorough recovery from his present illness.

Mr. R. W. Allen, in seconding the motion, said that Dr. Maw had expressed the thoughts of the Council on the motion that had been proposed. Speaking as a lay member who had attended many Meetings under Sir Frederick's Presidency, he had been struck with two aspects of his character, namely, that he was a leader of men, and was imbued with a great sense of duty. His duty to his country, in view of the great position he held, had prevented him from attending to his Presidential duties in the way he would have desired under normal circumstances. During the past two years the President had fully upheld the dignity of his office. He had been courteous and fair in dealing with the Meetings, and at the same time he had been a great host. He was certain that every one who visited Cambridge two years ago would remember Sir Frederick's kindness and affability, which qualities were so essential if such functions were to be a success. It was always a difficult matter to propose or second a vote of thanks, and he experienced a great

(Mr. R. W. Allen.)

difficulty on the present occasion in finding words adequately to express the thanks which were due to the President, but he felt certain that Sir Frederick's name would live amongst them as one of the most popular Presidents the Institution had ever had.

The PRESIDENT said that, as a member of the Council during the Presidency of Sir Frederick Donaldson, he was able to speak to the extreme care he took in dealing with the affairs of the Institution and the value to the Council of his sound judgment and great experience. He did not think any President had ever been more careful in conducting the work of the Institution than Sir Frederick Donaldson.

The Resolution of Thanks was then put, and was carried with acclamation.

The following Paper was then read and discussed :—

"Convertible Combustion Engines"; by ALAN E. L. CHORLTON, *Member*, of Lincoln.

The Meeting terminated at Ten o'clock. The attendance was 101 Members and 48 Visitors.

Mr. CHORLTON's Paper was read and further discussed at :—

BIRMINGHAM, at the Medical Lecture Theatre of the University, on Thursday, 25th February 1915. Sir GERARD A. MUNTZ, Bart., *Member of Council*, presided, and 30 Members and 37 Visitors were present.

MANCHESTER, at the Engineers' Club, Albert Square, on Friday, 26th February 1915. In the absence of any Member of the Council, Mr. DANIEL ADAMSON, *Member*, the Chairman of the Engineers' Club, presided; 79 Members and 36 Visitors were present.

CONVERTIBLE COMBUSTION ENGINES.

BY ALAN E. L. CHORLTON, *Member*, OF LINCOLN.

The advance in the use of the Internal-Combustion Engine for all duties becomes yearly more marked, and in the last decade, particularly the latter five years, it has been almost phenomenal, as exemplified by engines of the higher compression type, using fuel oil. In the United Kingdom, where it would seem coal must always be the basis fuel, the popularity of the oil-combustion engine must naturally be restricted, except for special duties and conditions called into being, perhaps by fashion, or the alarm caused by the interruption of the coal supply, due to artificial conditions, such as strikes. At the same time, the conveniences in the use of oil are so noteworthy that they are bound to claim serious consideration in almost all cases, even where coal is the basis fuel.

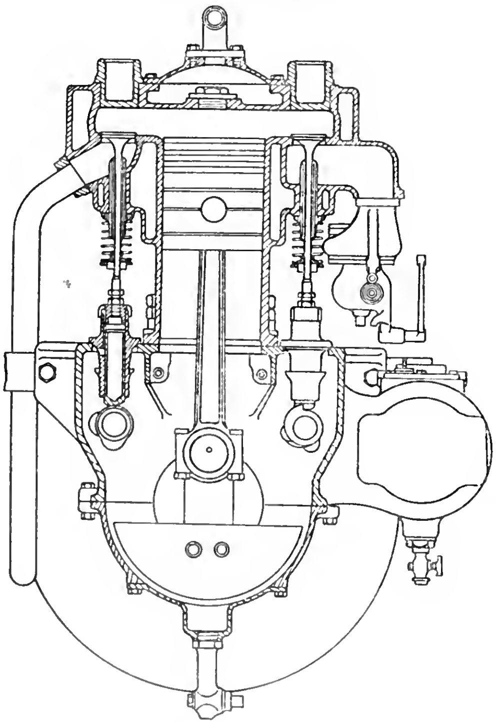
It is not the object of this Paper to advance the claims of either the gas- or the oil-engine, but rather to direct attention to the possibilities of a convertible engine designed to use advantageously both gas and oil. In surveying the problem in general, one might at first sight say that the combustion engine most ready to work on differing fuels would be of the self-ignition type, with a cycle approximating to that of constant pressure, in which the heat of

compression is always sufficient to ignite the incoming fuel, whether solid, liquid, or gaseous, and the only change necessary in going from liquid to solid would be in the fuel-injection device. In practice, however, owing to the difficulty with solid fuel injection, such a type would not prove workable, and even when the fuel is first gasified the results do not justify the complication. Thus this type, whilst highly successful on oil, must suffer a radical conversion to use coal. The problem of designing an engine is better met, especially on the grounds of simplicity and suitability for everyday use, by trying to combine known types for gas and oil in which good results are obtained at the present, and which, in general principles, show the same characteristics.

Many of the types of engines in everyday use will therefore be considered, as well as other methods presenting advantageous possibilities. In the normal engines for both gas and oil, the chief difference lies in the degree of compression. Thus the compression of a modern gas-engine using coal as its basis fuel may vary from 90 lb. per square inch, when using coke-oven gas, to 150 lb. per square inch for producer-gas (and even higher if waste gases are used from blast-furnaces, etc.). Whilst for the liquid fuel engine, using crude or residual oils, the compression pressure may exceed 500 lb. per square inch, as in the case of a Diesel engine using tar-oil, but may be considerably less if the temperature of ignition is obtained by uncooled surfaces, or auxiliary or pocket firing used.

As there is no fundamental difference in engines for gaseous or liquid fuels, except in their conventional cycles, it follows that any schemes of convertibility must provide means whereby the requisite compressions can be readily obtained, but as between 500 and 150 lb. there is a great gap, the tendency is for practical reasons to combine the lower compression oil-engine and the higher compression gas-engine, and thus deal with a smaller compression pressure range. The problem is mainly a mechanical one, in and around this change of compression, and a combination from a judicious selection of well-known types which have proved successful with their various fuels. Though the convertibility may be affected somewhat by the cycle—that is, whether two or four—it may be taken generally that the

FIG. 1.—*Diagram of Ordinary Motor-Car Engine using various fuels.*



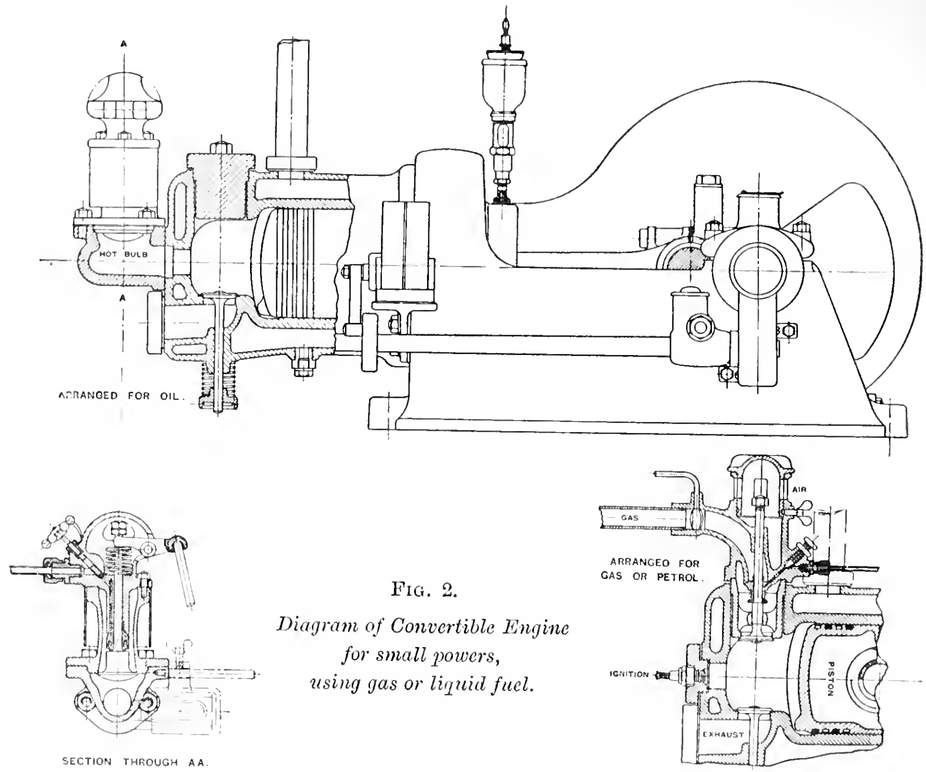


FIG. 2.

Diagram of Convertible Engine for small powers, using gas or liquid fuel.

degree of compression is the governing factor. The desirable characteristics of the convertible engine are:—Simplicity and reliability; economy should be high for each fuel; first cost as little as possible above that of the standard engine for each fuel; easy convertibility; as near as possible the same power developed for each fuel.

The consideration of the subject may be more clearly undertaken by dividing the types of engines in use into three groups, with further subdivisions, due to peculiarities of design:—

(1) Engines of low compression and low power.

(2) Engines of high compression and higher power.

(3) Engines of medium compression and higher power.

Group 1.—As an example of the first group, we may take the ordinary motor-car engine, Fig. 1, having a compression up to 90 lb. per square inch, and which, with slight modifications, will run on:—

(*a*) Petrol or benzole.

(*b*) Good paraffin with an exhaust heated carburettor.

(*c*) Town gas.

(*d*) Producer-gas made from coal or waste combustible materials.

It is designed for and works best on petrol; fairly well, however, but not so economically, on town gas; it requires very good paraffin; and is not efficient at the low compression with producer-gas.

To go further and extend the range of fuels, to use a commoner paraffin or a good brand of crude oil, means must be provided whereby more heat is available for the ignition and combustion of the oil, and this can be conveniently done by the addition of an unjacketed portion to the cylinder end, when the engine becomes of the hot-bulb type. A change of parts for such an engine does not present any difficulties, and these can be readily made to give with any adjustments of compression necessary for the producer-gas with the greater heat required for ignition and combustion of the oil. The gas fittings are provided with electric ignition, also suitable when petrol is used, whilst the paraffin and good crude oil would be self-ignited by the hot bulb. Fig. 2 illustrates the practical

application of these modifications. The engine illustrated was lately built with success to work on all usually available fuels, for small powers, and such a type can be changed by unskilled labour (maybe a farm hand) from a gas-engine working with a wood or coal producer, to an oil-engine using a good brand of Russian crude oil, the governor requiring no adjustment for the full range of fuels.

A comparative commercial Table of the results obtained with this engine, is :—

——	Compression.	Max. Pressure.	M.E.P.	B.Th.U. per b.h.p. hour.
Paraffin oil .	55	210	58	14,500
Producer-gas	90	230	65	12,000

Fig. 2 shows the gas- or petrol-engine with electric ignition, also the oil-engine, a hot-bulb being added in the latter case and ignition obtained thereby.

This type of engine is not suitable for any but comparatively low powers, and the range of fuels does not include one heavier than good crude oil. Further, its economy on oil is not high. It is mainly described here as it contains the basic principles of a more suitable engine for large powers. Further modifications must therefore be made, in order that the fuels of poorer quality may be used, and this for any range of power. These conditions demand an engine having a considerably higher compression for the fuel and residue oils, and in the second group we have engines with high compression and higher power.

Group 2.—This group is represented by the Diesel engine, with a compression of over 500 lb. per square inch, when using tar-oils (unless an ignition oil is used). As the maximum compression for gas (in the normally used type of engine) does not exceed 150 lb. per square inch, it will be readily seen that there are considerable mechanical difficulties in building an engine in which both of these compressions can be obtained, with a reasonable amount of modification. Further, the Diesel engine has an expensive

high-pressure air-pump, which is unnecessary for the ordinary type of gas-engine.

Apart from the mechanical difficulties, the commercial possibilities of this type may be compared, the oil and gas sides being as follows for engines of the same cylinder dimensions :—

——	Compression.	Abnormal Max. Pressure.	M.E.P.	Approx. B.Th.U. per b.h.p. hour.
Oil-Engine	500	Over 1,000	100–110 lb.	8,000
Gas-Engine	150	600	80 lb.	8,500

These figures show how incompatible the two designs are, for they illustrate that the Diesel structure must be built twice as strongly for the very high maximum possible pressure, due to the fuel-valve sticking, etc. The higher M.E.P. used is some compensation for this extra cost and weight. The mean cylinder pressures reveal a still further disadvantage when the gas conversion is considered, for there is, besides this high first cost, a reduced power, owing to working at a lower M.E.P.—80 as against 100–110 lb. per square inch. A convertible engine on these lines does not seem a commercial possibility. The cost of the air-compressing part of the Diesel has not been considered, nor has the working of the gas-engine on the Diesel cycle, for this alternative, at any rate at the present date, is not a commercial proposition. (The net efficiency may be actually lower, due to the loss in the gas compression ; and the risks of working greater.) Although it is of the utmost necessity that any lasting type of prime mover must have in these days as its essential feature economy in fuel, it is still not the only point, for reliability and simplicity must be equally considered. Whilst, therefore, recognizing the economy of the high compression self-ignition engine, we are compelled to look to one of the other types described as a more suitable combination for everyday use.

Group 3.—This group comprises engines with a moderate compression suitable for developing higher powers. The range of

the compression of these engines lies in between that of Groups 1 and 2, and usually is from 150 to 300 lb. The compression of 150 lb. is suitable for most forms of producer-gas, but it is not usually exceeded, for the reason that pre-ignition of the compressed charge is more prevalent in very high compression gas-engines. On the other hand, it is necessary for all compressions below self-ignition compression, as in the Diesel, to employ some auxiliary means to obtain the necessary height of temperature for the proper combustion of the residue oil. Normally, as in the second engine, Fig. 2 (page 157), the additional heat is obtained by an unjacketed surface or combustion bulb at the cylinder end. This temperature-raising device is employed, with other agents, to give the best effects, on the score of economy; for the lower compression, such as 150 lb., a satisfactorily running oil-engine is obtained; the economy, however, is not quite so high and the range of fuel not so fully extended.

The various devices employed in and around the question of temperature, compression, and convertibility of this group of engine, may be considered by subdividing it under the following heads:—

(*a*) Engines working with a compression not exceeding 150 lb. both for oil and gas, and which may employ pocket-firing with or without air-injection for one, and electrical ignition for the other, or some combination, the smaller compression not involving material mechanical change of the parts.

(*b*) Engines working with a higher compression for oil than gas, involving some modification of the combustion chamber by substitution of a part for oil as against a part for gas; otherwise maintaining the simplicity of both types.

(*c*) Engines obtaining the necessary change from gas to oil by temperature control of the air charge, together with alteration of the valve settings.

(*d*) Engines employing the super-compression of Dr. Dugald Clerk, to control effectively thereby the compression required for either fuel. (Final ignition temperature by other means.)

Under subdivision (*a*) there is a large number of engines which are used only for oil, but which might, without material alteration, become effective in the use of gas, although the whole combination is not as efficient as the highest individual member. As an instance of this division, there is the two-cycle Bolinder engine, at present only used for oil, although originally used by Day for gas, Fig. 3. When made with a stepped-piston, as in Fig. 4, with uncooled cylinder-head substituted by a water-cooled one, a gas-engine for small powers is more or less effectively obtained.

Sketches of two-cycle Engines.

Fig. 3.—*Vertical Type (Bolinder). Arranged for Oil.*

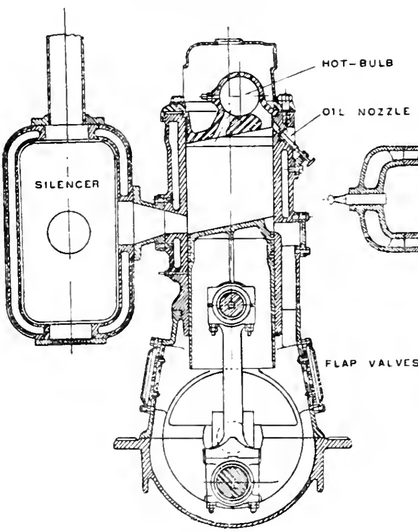
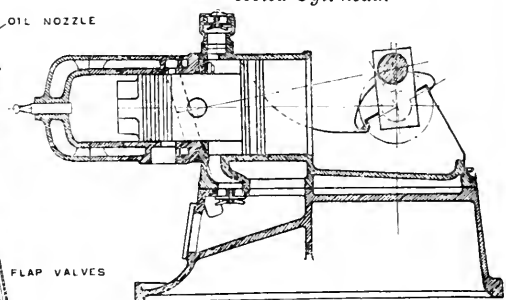


Fig. 4.

Horizontal Type. Arranged for Gas. With Stepped-Piston and water-cooled Cyl.-head.

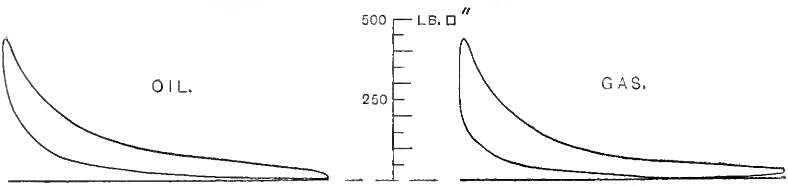


For larger powers it is usual to separate the air and gas in the pump, and the engine becomes therefore not quite so simple a proposition to change over from the use of oil to the use of gas. In the four-cycle engine, the change from oil to gas involves a removal of the unjacketed part of the combustion head for that of a gas type, with electrical ignition.

A variation of this type, employing air-injection for the fuel, combined with pocket-firing for the ignition of the charge, secures

considerable economy when used with oil. The advantage, however, in using more or less the same compression for both oil and gas is lost through the need of a high-pressure air-compressor (as with the Diesel) and the employment of double-injection needles. For higher powers and the best economies, it is necessary to go considerably further, for, unless the economy upon oil is approximate to that of the Diesel engine, the convertible type will not become of any real lasting value.

FIG. 5.—*Engine Indicator Diagrams. (Traced from Cards.)*



In considering the next division, namely (*b*), a useful comparison of its possibilities is given in tabular form, for engines of the same cylinder dimensions:—

——	Compression.	Abnormal Max. Pressure.	M.E.P.	B.Th.U. per b.h.p. hour.
Oil-Engine	250/280	600	80	8,100
Gas-Engine	150	600	80	8,500

It will be seen from this that the outputs and general figures relative to the engine bear a great similarity. Further, as in Fig. 5, the diagrams actually taken when running on oil and gas are also shown to be of very similar nature. The possibilities, therefore, of this type of convertible engine appear, from these indications, to be very great; and an engine which has at present been made in considerable numbers to fulfil these conditions is shown in Figs. 6 to 8 (Messrs. Ruston, Proctor and Co., Ltd.). These show clearly that in both cases the engine presents the ordinary features of the four-cycle engine, and the only change

FIG. 6.—*Diagram of Cylinder, Flywheel, etc., of Convertible Engine.*

Fig. 7.—When using Oil.

Fig. 8.—When using Gas.

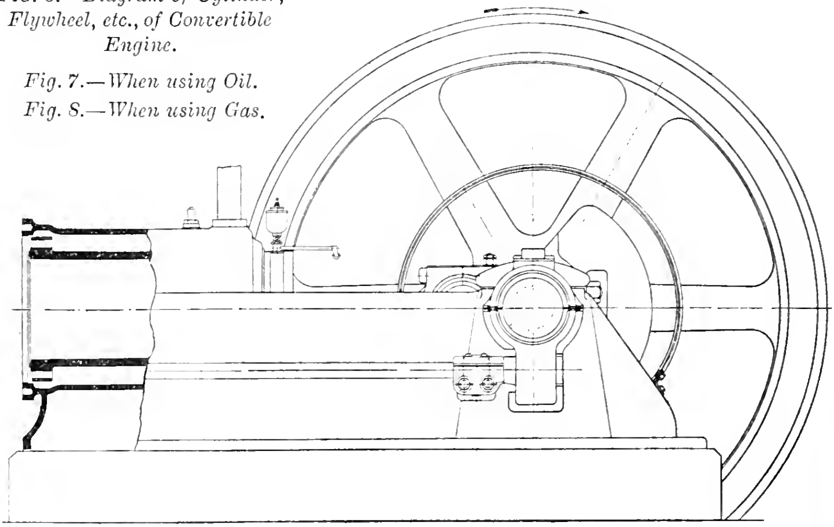


FIG. 7.

Arranged for Oil.

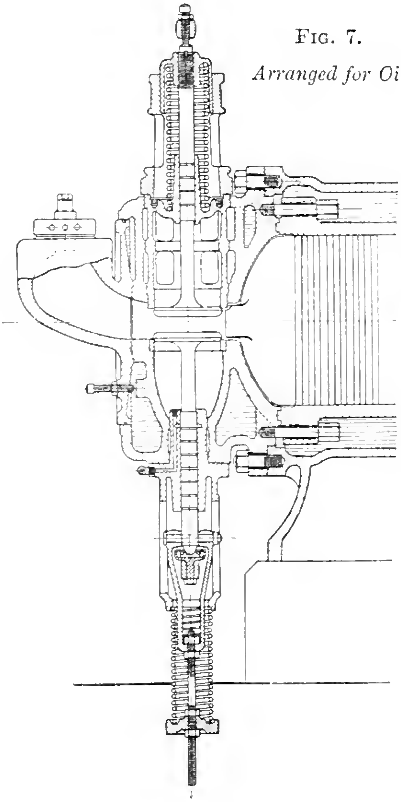
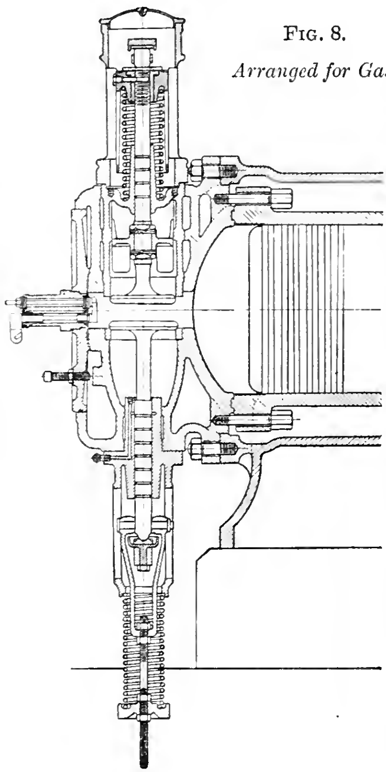


FIG. 8.

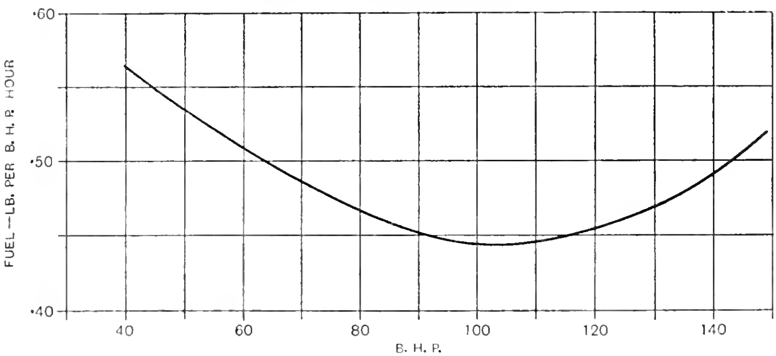
Arranged for Gas.



involved in converting from oil to gas lies around the combustion bulb of the oil-engine, in which the fuel-oil is injected, and in the change from an oil-type to a gas-type piston.

Fig. 7 indicates the arrangement of parts when running on oil, and Fig. 8 when running on gas. As the essential feature of the convertible engine (as has been pointed out) is that it must maintain the economy when on either fuel, the curve is given in Fig. 9 showing the consumption of this type of engine when running on Russian crude oil. On gas, where it is seen that the engine resembles the well-known four-cycle type, the consumption figures

FIG. 9.—*Consumption Curve of* 130 *B.H.P. Engine* (*Fig.* 6). *Fuel—Russian Crude Oil.*

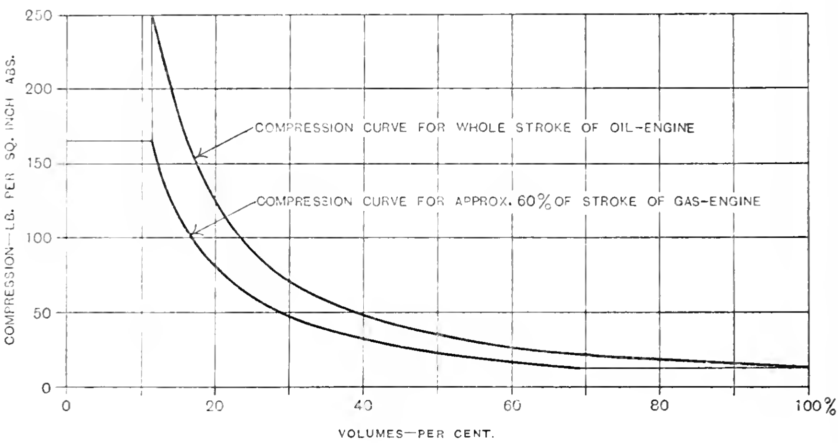


are in parallel with those which have been taken on various occasions by different experimenters.

Group (*c*).—The use of the arrangements grouped in this division may be said to be one of mechanical and constructional convenience, for they can hardly be defended on the score of efficiency. In one method the jacket of the cylinder-cover or breech-end is formed to withstand a pressure, and is worked in the manner of a boiler. The increased heat is impressed in the charge of air during the compression stroke to raise the temperature sufficiently to afford ignition. This arrangement thus replaces the hot-bulb or unjacketed end of the cylinder. It has some advantages, in that it is perhaps

more controllable and the steam generated may be used for some useful purpose, perhaps in conjunction with an exhaust-heated boiler for an auxiliary steam-cylinder on the main engine. The water injection of some hot-bulb engines is also done away with. This type of engine is unusual in practice. When in use as a gas-engine, such a convertible engine would have to dispense with the pressure-jacket temperature when using the lower compression and temperature needed for such an engine. Actual heating of the inlet air may be a practical convenience for dealing with a

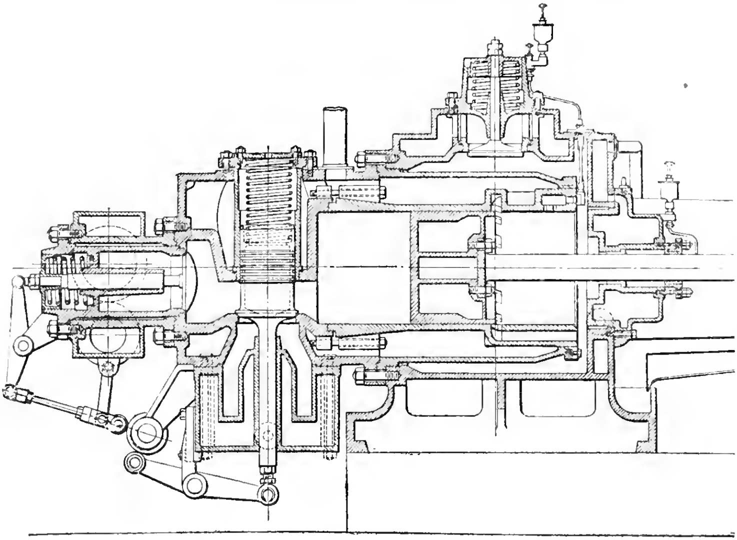
Fig. 10.—*Valve-Setting. Compression Curves for Oil and Gas.*



particularly refractory oil not amenable to the available compression of the engine. The valve-setting of an engine may be modified, as in Fig. 10, to give suitable compressions for oil and gas; this can be worked in conjunction with the temperature arrangement just described. The gas-engine suffers in loss of output, as is shown in the diagram.

Group (*d*).—The Clerk super-compression engine is a much more suitable and promising type for dealing with the variable compression problem of the convertible engine. In this engine,

FIG. 11.—*Diagram of Super-Compression Engine.* (*Clerk.*)



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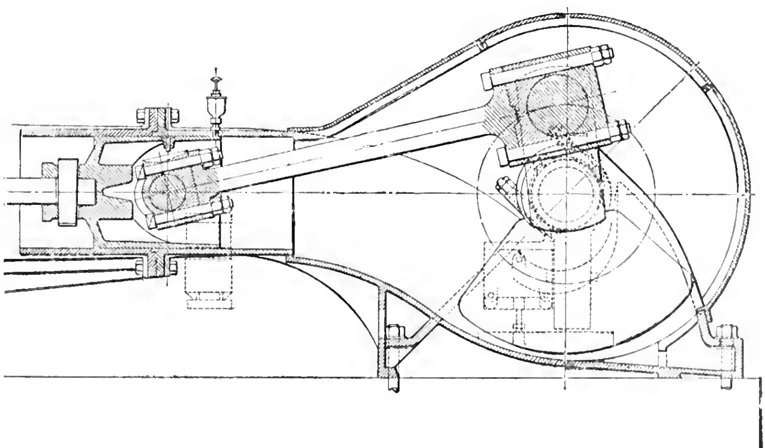
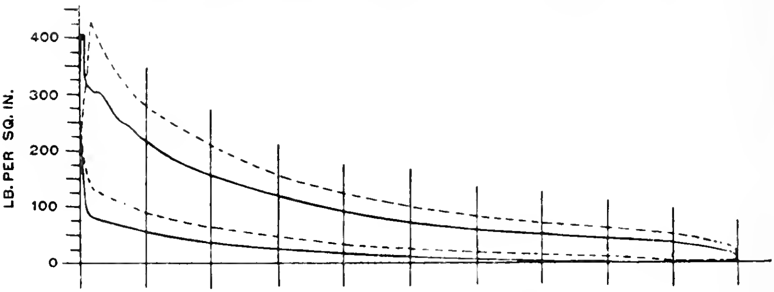


the principle of which is probably well known (an actual engine built some years ago being shown in Fig. 11), an extra charge of air or inert gas is added to the working mixture at the end of the suction-stroke. By this means, owing to the, so to speak, "watering" of the charge, much lower maximum flame temperatures are obtained and a higher mean cylinder-pressure rendered possible. For the purpose of the convertible engine, it is mainly suitable, as by varying this amount of added air the compression can be adjusted between wide limits, the final temperature being controlled by any of the previously indicated means. For instance, with a compression of 300 lb. maximum, the full displacement of the air-pump may be used; for the lower compression of the gas-engine one can, by any

FIG. 12.—*Indicator Diagram. Super-Compression Engine.* (*Clerk.*)



suitable valvular means, as an ordinary by-pass, reduce the amount of discharge as required.

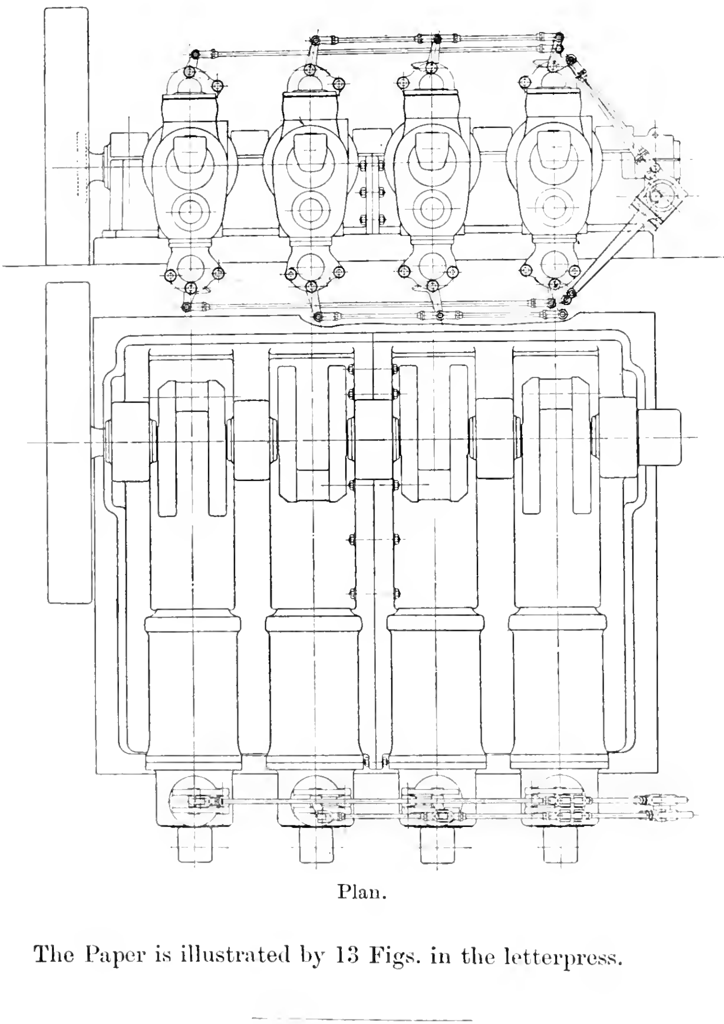
The commercial value of this type has hardly been determined in practice, but it would almost appear that its possible usefulness will only come in for large engines, for after all it is an addition, if not a complication, to the ordinary engine of everyday use. The diagram of such an engine, from one of Dr. Clerk's Papers, is given in Fig. 12. The engine really uses a two-stage compression, but not expansion.

The conclusion the author arrives at is that, for powers up to say 1,000 b.h.p., the type of engine represented by the "Ruston," Class B, Fig. 13, is the most suitable as a convertible engine, whilst for still larger powers, when tandem engines and size and weight

of removable parts become a problem, the Clerk super-compression type offers very interesting and hopeful possibilities.

FIG. 13.—*Diagram of 4-cyl. 520 B.H.P. Oil Engine.* (*Ruston.*)

Elevation.



Plan.

The Paper is illustrated by 13 Figs. in the letterpress.

Discussion in London.

The PRESIDENT, in proposing a cordial vote of thanks to the author, said the Paper dealt with a subject which was a novel one to most of the members, but which looked as if it had not an inconsiderable importance from the commercial point of view. The Paper was of very great interest, and he hoped it would evoke a good discussion.

The Resolution of Thanks was carried by acclamation.

The PRESIDENT stated that it had been hoped that Dr. Dugald Clerk would have opened the discussion, but a telegram had been received from him saying that he was very sorry that he had been prevented from attending the Meeting.

Mr. W. A. TOOKEY, in opening the discussion, said that although the author had demonstrated what might be called the constructional practicability of a convertible combustion engine, he had not dealt, to the extent that one would have wished, with the question of whether such an engine would be practically possible, and still less had he dealt with its commercial value. It might be a more or less easy matter to make a convertible combustion engine, but the point that always had to be kept in view was the position it would take in the engineering world. Naturally, when two fuels, oil and coal, were being dealt with, the question of the gas-producer was interposed. In the relative figures given in the Table (page 163), the author had taken the thermal efficiency of the oil-engine as 8,100 B.Th.U. per b.h.p. hour and of the gas-engine as 8,500. Town gas, however, would rarely be used for an engine of any considerable size, and an engineer would hardly think it worth while commercially to convert a small engine from one fuel to the other. Therefore, as he had previously said, the producer must be interposed; and although proof had been obtained that

the gas-producer would give fuel-to-gas efficiencies of 80 per cent., yet in order to cover the leakages or waste due to sifting of the fuel, standby losses, and things of that kind, he thought, from a commercial rather than a technical standpoint, it would be much more correct to take the efficiency of the producer for that purpose as being of the order of 75 per cent. On that assumption, the figure of relative thermal efficiency would be 8,100 for oil and 11,300 for coal, in B.Th.U. per b.h.p. hour.

It was advisable, he thought, to gain some idea as to the relative value in an engine of a ton of either fuel, for when a note had been obtained as to the relative costs, it would then be possible to form an idea as to the probable commercial value of a convertible engine. It would be possible by such means to ascertain whether any saving resulting would cover the actual cost of the conversion. After all, it depended upon whether an engine was being converted from gas to oil or from oil to gas. It might be taken that petroleum gave roughly 18,000 B.Th.U. per lb., whereas good anthracite coal gave about 14,000 B.Th.U. per lb., so that a ton of oil would give 40,000,000 B.Th.U. and a ton of coal 31,000,000 B.Th.U. Those were very big figures, but they meant that when the toll of the producer was taken into account, oil had a greater advantage on the ton basis to the extent of a ratio, expressed by oil divided by gas, of 0·716. That was a useful figure to keep in one's mind, because it gave a basis for considering the commercial possibilities. Taking the size of engine which the author had referred to as 130 rated b.h.p., and presuming the engine would run normally at a mean load of about 100 b.h.p., it meant that, working for 3,000 hours in the year at 100 h.p., about 60 tons of oil or 108 tons of coal would be burned. Those values would be equal, on the basis he had suggested, if oil were obtainable at 42*s.* a ton and coal at 30*s.* a ton. Those were roughly the relative market prices they could afford to pay for equal operating costs for fuel only. There must therefore be a very considerable variation, either in the cost of oil or in the cost of coal, before they could afford to pay the amount that would be involved in converting an engine from one type to the

(Mr. W. A. Tookey.)
other. The author had stated that a new piston would have to be used, and those who had had practical experience with gas-engines knew it was sometimes not a wise thing lightly to undertake to change the piston of an engine after it had been working for some time, especially when it meant that the piston would have to be either longer or shorter, and therefore bring the wear on a different part of the cylinder. That was quite a practical point which must be borne in mind, although for the moment he was only dealing with the question of the commercial value. Supposing that 80*s.* per ton of oil and 30*s.* per ton of anthracite were taken, it would be found that, on the basis he had given, provided that everything went well and that there was no hitch, a saving would be obtained in one year of £77. Out of that saving a deduction would have to be allowed for the cost of conversion, which, with a new piston and other gear, labour, etc., for an engine of the size mentioned in the Paper, might possibly amount to about £50 or £60. By the time that amount had been saved, it was possible that the 80*s.* per ton for the oil might have been brought down to a little less, or the coal figure might have varied in the same way. He would like to know whether the author had dealt with the matter on the basis he had suggested. Personally, he quite accepted the fact that it was constructionally practicable, but was it likely to be commercially valuable; in other words, whom would it pay? Which class of user had the author particularly in mind when he put forward the idea of a convertible combustion engine?

He desired, in conclusion, to mention one point arising from the reference to Dr. Clerk's super-compression engine. He knew very little about this particular engine, but, apart from super-compression, had the author considered the utilization of a certain proportion of the exhaust gases escaping from the engine cylinder and introduced with the new admission charge, such as was done by the engines provided by one well-known firm for working with coke-oven gas which had a high calorific value with a high percentage of hydrogen, and therefore presented a great similarity to the oil mixtures which were used in a high compression or a "semi-Diesel"

oil engine? The added exhaust-gases had a very useful effect in decreasing the rapidity of ignition of otherwise highly inflammable gas-mixtures, and thus might be of equal service for convertible combustion engines, such as were described in the Paper.

M. R. Mathot in the first place desired to apologize for his small knowledge of English, but he was more proud of the little English he knew than if he had a first-class knowledge of the German language. He desired to ask for a further explanation of the Table on page 159. He noticed that in the second line of the Table the B.Th.U. for a producer-gas engine were given as 12,000 per hour. If he understood that correctly, it meant a thermal efficiency of 20 per cent. Did that relate to the gas or to the coal itself, because if it related to the gas it was rather a low figure, and it was not a great encouragement, in following the scheme proposed by the author, to converting an oil engine into a producer-gas engine?

He wished to know, from the author's personal experience of the semi-Diesel engine of the two-cycle type, how he proposed to deal with the conversion of such an engine from liquid fuel to producer-gas or town gas, and whether it did not involve the replacement not only of the piston but of the breech-end and certain other parts. He also desired to know to what extent of power the author thought the convertibility of the engine from oil to gas, or from gas to oil, was practicable, presuming that the constructional proposition was a commercial one. From the information he had been able to derive from the Paper, it seemed to him it must be confined more or less to small engines not above 10 or 20 h.p.

Mr. F. H. Livens thought the Paper should be looked upon rather as suggestive of what might be future developments, although it also correctly described what had already been done. It was really an outline to be filled in by those who had that kind of work to carry out. If half a dozen people who were not accustomed to the design and manufacture of engines were asked whether it was possible to convert a gas-engine into an oil-engine, or vice versa, he had no doubt whatever that five out of six would at once say it was

(Mr. F. H. Livens.)
quite possible; he thought probably all the six would. He was also quite sure that if half a dozen people who had had long experience in the construction of oil and gas engines, and knew the difficulties connected with them, were asked a similar question, a different reply would be received, particularly if they were asked whether it was possible to change an engine having a compression of 120 lb. when using gas into a serviceable crude-oil machine having a compression of 280 lb. The problem was thus shown to be open to a good deal of discussion.

He thought it would be of interest to the members if he told them how the engine shown on page 164 came to be designed. It was not a fact that, in the first instance, the idea was to supply to any user an engine which he could convert from gas to oil, or vice versa, just as he pleased. The particular design shown in Figs. 7 and 8 came about through the requirements of the oil-fields. Those who were acquainted with the oil-fields knew that the bore-holes were put down at very small distances from each other, and that sometimes a great deal of gas came up with the oil. On the other hand, sometimes there was very little gas. But if gas were available it was used, because otherwise it went to waste, and oil during the last year had become very valuable. A few years ago nothing but steam was used upon the oil-fields. Where gas existed, it was burned under the boilers; where there was no gas, or of not sufficient quantity, then crude oil was so burned; that system was now to a large extent being superseded.

It happened also in oil-fields that were only a few miles apart that one would have a rich gas in plenty, and another would have hardly any. If the gas could be piped, and brought where new bores were being put down, it was naturally very convenient to have an engine which could use the gas. If, on the other hand, gas was not present, it was much more convenient to bring oil by a small pipe-line to the place required and use oil. Supposing a bore were complete, and both gas and oil were available, then it was most economical to use gas and sell the oil. It might, however, happen, and did happen, that the gas "petered out," and then the user must fall back upon oil. That was the origin of this particular design some

four years ago when the question was brought to his attention, after investigation and a visit to the countries concerned. It was a fact, therefore, that a good heavy-oil engine could be constructed which could also be made to use gas advantageously. Speaking as a manufacturer who sent such machines into many countries of the world, the term "gas" meant many qualities, and had a wide application. There was, first, the gas obtained from a producer, say a poor gas with perhaps 160 B.Th.U. per cubic foot; secondly, a town gas which contained perhaps 650 B.Th.U. per cubic foot; and, thirdly, there might be, as existed on the oil-fields, a natural gas which contained up to 1,050 or 1,060 B.Th.U. per cubic foot. So that for commercial purposes, for the convenience of the user, it was useful for the manufacturer to be able to supply a machine which would meet all needs, whatever they might be. M. Mathot was perfectly correct when he stated that the ordinary low-compression engine could not be converted with any great advantage, except for small powers.

He had not quite followed Mr. Tookey in his argument as to the difference in economy. A producer-gas engine would work very successfully with about a pound of coke per b.h.p. hour, a crude-oil engine of the type to which he was referring would work with a consumption of about half a pound of oil per b.h.p. hour, so that the fuel cost when using coke, presuming oil to be 70*s*. per ton, was just about half. He desired to give an instance in which it might be convenient for the user to change his engine. Supposing, for good reason, a manufacturer put down an oil-engine, and then, as conditions altered, he wished to use gas, and put down a producer, by so doing he would save half his fuel cost. The other point which had been mentioned was that, where small engines were supplied, it was a great convenience to be able to change from one fuel to the other without sending the engine back to the manufacturer's shop, and if the agent could stock the engine and parts, the change could easily be made.

As he had already said, the Paper dealt with possible developments in a very large trade not confined to this country, and in criticizing the Paper, and in following out the lines of

(Mr. F. H. Livens.)
thought, it should be considered from the point of view that engineers had to make such engines to fulfil many conditions and to send them to many parts of the world. Therefore, whilst he was free to admit that, if it was desired to make the most perfect oil-engine or the most perfect gas-engine for a particular gas, more modifications would be required in the design than were apparent in the Paper, he contended that for a great many purposes the engines described in the Paper were practicable. It would be appreciated at once that, where natural gas was being used, a slightly greater consumption was of no particular moment, and the same remark applied where a poor gas like a producer-gas was being employed. Therefore, in the first instance, the engine should be designed perfectly to use crude oil, and then the changes be made in the most economical manner in order that it might use gas.

Mr. E. W. Petter said that there were one or two questions he would like to ask. As an ardent disciple and firm believer in the two-cycle type of engine, he was most interested in Figs. 3 and 4 (page 162), and he was sorry the author had dismissed that type of engine with so few remarks, as many of the members would have been very interested if particulars had been given of the results the author had obtained, assuming he had actually made experiments on the designs shown in the Paper. He was not sure, from looking at the figures, whether the engine had actually been made, and he would like to know if that was the case or not. It would also be of interest if the author would say what he meant by the statement, "A gas-engine for small powers is more or less effectively obtained." What did he mean by "small powers"?

Mr. Livens had dealt with a point which was very much in his mind, namely, that a much greater alteration to the engine than was shown in the diagram was evidently necessary to make it work with gas. All manufacturers of oil-engines quite understood the object of the Paper, as explained so clearly by Mr. Livens. They were frequently asked, for special conditions, to provide engines which would work and change over from gas to oil, and apart from

any question of whether they were applicable to domestic or farm use at home, there was no doubt that an engine which really gave approximately the same results with both fuels had a great field before it. If the practical difficulties could be overcome, he thought the two-cycle type of engine lent itself very much to the change over, because the compressions, as stated in the Paper, were approximately, or even exactly, the same.

Referring to Figs. 7 and 8 (page 164), he noticed from the Table on page 163 that the compression in the gas-engine was reduced from 250/280 to 150 lb. per square inch. He could not see from the illustrations how a reduction occurred; it appeared to him there was an increase in the compression, and he would therefore be glad if the author would be kind enough to explain the point further.

Mr. E. M. GIBSON said he represented a different class of user from those who had previously taken part in the discussion. In the works of his firm in Russia two 400-b.h.p. Körting type of gas-engines, made by Messrs. Mather and Platt, Manchester, which were really the author's children, had been installed. In the previous year, owing to the War, the export of coal from England to Russia was first of all curtailed and then stopped altogether, and a considerable portion of his firm's coal that was lying at Kronstadt was commandeered by the Government. Owing to trouble in Scotland, they could not get their usual brand of Scotch coal for producers, and as a result had to use wood in the boiler-house, eking out the remaining stock of producer-gas coal with ordinary coal. He was glad to say that had proved successful, but if the War went on for another six months he did not know what they would do to keep their gas-engines running. If the author could assure him that he had some practical means for converting these gas-engines to oil-engines, he would be very pleased to give him a provisional order on the spot.

Mr. HORACE BOOT said that Mr. Livens had answered most of the questions he had intended to ask. Users of oil and gas engines

(Mr. Horace Boot.)

naturally wanted to know what the reliability would be if a change over were made. It would be an advantage to manufacturers if they could stock one type of engine, and, by a few changes, make an oil-engine suitable for a gas-engine or vice versa, because it ought to have the effect of reducing the prices of both types of engine. He had had some experience of the running of the particular oil-engines mentioned, as he had placed some of them on a rubber plantation. Those engines had been running with considerable success without any skilled attention whatever, as the natives had looked after them.

With reference to Fig. 9 (page 165), he did not quite understand why the particular engine referred to was apparently much more efficient in its consumption at about 105 b.h.p. when it was built for 130 h.p. He was aware that in all types of gas and oil engines it was always advantageous to run them at slightly less than their full load if reliability was to be obtained, but there was a considerable difference in consumption in the engine described in Fig. 9, which was not noticed to such a large extent in the particular engines that were built to his own specification. He was of the opinion that the consumption of oil per lb. per b.h.p. was slightly more than that given in Fig. 9, but probably, since his engines were ordered and sent out, the type of engine had been improved upon. He was able to say, however, that so far as oil-engines of the design shown were concerned, they worked satisfactorily, and had given no trouble during the years they had been in use.

Mr. WILLIAM H. PATCHELL (Member of Council) asked the author, in replying to the discussion, to state what he meant by the words "low power" and "higher power" that were used on page 158; in other words, what was the classification adopted, because as these terms stood in the Paper they were a little difficult to understand? The author in reading the Paper had apologized for its being so very short. In the present busy and strenuous times most people liked things in tabloid form, but it was necessary to see that the label was clear. He also desired to draw

attention to the statement just made in amplification of the Paper by the author's colleague, Mr. Livens, that if a manufacturer wanted to save money he should first of all buy an oil-engine and later on convert it to a gas-engine. But could he save money in that way? He might save money on his fuel, but he would not get the oil-engine for the price at which an equivalent gas-engine was sold, unless a very different price list existed from what he had often seen. It must always be remembered that the cost of the fuel alone did not regulate the cost of the power. The suggestion reminded him of what they heard some years ago, and had heard again during the past year in London: "If you will only trust me, I will give you electricity at a halfpenny a unit"; but the vendor did not stop and tell people what were their commitments before they would get the electricity at a halfpenny a unit! The capital costs were highly important, and he thought the purchaser would probably have been considerably out of pocket if he had included his capital charges in the cost per b.h.p. hour.

Previous speakers had referred to the thermal efficiencies given in the Paper, and he thought it would be useful if the author would make it a little clearer as to whether they were based on gas or on coal. Some of the largest and best gas-engines that had ever been installed in England ran on about 10,000 B.Th.U. per kw. hour, which, with a good efficiency on an alternator, was about 8,000 to 8,500 B.Th.U. per b.h.p. hour. But that was based on the gas alone, and not on the thermal value of the coal; in many cases the efficiency of a producer entered into the question and was a very important feature, as mentioned by Mr. Tookey. If the author had time to amplify these points in his valuable Paper, he thought it would be still more useful.

M. R. Mathot asked the author whether, in his experience, it was simpler to convert a gas-engine into an oil-engine than an oil-engine into a gas-engine, and what possibilities there were for those two kinds of conversion. He supposed that both methods of conversion could be carried out, but he would like to know which of the two was the more economical. For instance, shoes could

(M. R. Mathot.)
always be converted into slippers, but it was difficult to convert slippers into shoes.

Mr. MICHAEL LONGRIDGE (Vice-President) said when he first read the Paper he was inclined to wonder where the market for the convertible engines described would be, and to think that conversion must simply be a device for manufacturing gas and oil engines in the same works at the cheapest cost, making one lot of patterns do for both types of engine. Mr. Livens, however, had explained that there was a market for these engines in the oil-fields; and on thinking the matter over further, it struck him that there might also be a market for small engines in out-of-the-way country places. In such places it was not always possible to get supplies just when they were required, and it might be convenient to have small engines which would work ordinarily with gas, and, if they ran out of gas, with oil, and vice versa. Again, where periods of variable and light load occurred at times, and a gas-producer was difficult to work, it might be useful to turn for the time to oil. But where small engines were used, they were generally run by attendants who knew very little about them, and could hardly be trusted to take out and replace a piston. Was it not possible to devise some means of altering the clearance volume on which the conversion depended, without taking out the piston? In the gas-engine the questions of the scavenging and pre-ignition had to be kept in mind in designing the breech end. There were not the same difficulties with the oil-engine. He would like to know if any experiments had been made with a view to reducing the clearance of the gas-engine by putting the hot chamber shown on Fig. 7 (page 164) inside the breech end, or to increasing the clearance of the oil-engine by adding a small chamber at the back of the breech end.

Captain H. RIALL SANKEY (Member of Council), in referring to the illustration M. Mathot had given of slippers and boots, said he would like to ask the author whether in engines of the same power the scantlings of an oil-engine (those of the crank-shaft, for instance) would not have to be greater than for a gas-engine. If that was

the case, then the oil-engine would be represented by the pair of boots and would have to be cut down to slippers to make a gas-engine, and vice versa it would be impossible to make the gas-engine into an equal powered oil-engine. That point was, he thought, well brought out in the Table (page 160), where it was stated that for an engine of the Diesel type the abnormal maximum pressure was over 1,000 lb. He thought if the author had said 1,500 or 1,700 lb. he would have been nearer the mark. It was obvious in that case that the scantlings of the Diesel engine had to be far greater for the same power than for the gas-engine, which explained the reason why such enormous crank-shafts and bolts to hold down the cylinder-covers were used in the Diesel engine.

He also desired to ask the author whether he had considered the question of altering the compression by altering the point at which the exhaust closed. Obviously, if the exhaust were closed less quickly, less compression would be obtained, which would do for the gas-engine; and by closing the exhaust at the beginning of the back stroke there would be a greater compression, which would do for the oil-engine. He knew that engines of that type had been proposed, but he did not know whether any had actually been brought into practical operation.

Mr. A. E. L. CHORLTON, in reply, desired in the first instance to thank the members for the kind reception they had given to the Paper. Mr. Tookey, who opened the discussion, dealt mainly with the Table on page 163, which had also been referred to by subsequent speakers, and had referred to the comparison of consumption figures in B.Th.U. between the oil-engine and the gas-engine. He inquired whether the figures in the case of the gas included the producer. They did not, and that was almost obvious from the figures in the Table. If they had included the producer they would have been the figures that Mr. Tookey gave. Mr. Tookey really answered his own query, because he went on to show that when the figures were reduced to a commercial comparison—the cost of the coal against the cost of the oil—it more than allowed for any loss due to the producer itself.

(Mr. A. E. L. Chorlton.)

Mr. Tookey then dealt with the possible uses of a convertible engine, and asked whether it would be worth while to make such an engine: would it pay for the extra cost of changing from one type to the other? For an answer to that question he desired to refer to the remarks Mr. Livens had made, who dealt with the subject very fully, and he had further explained that the Paper was really only a suggestion and did not discuss the whole situation with the various possible ways of conversion. He (the author) had not actually said so, but that was what it really amounted to. It had not been possible for him in the time he had at his disposal to go into the subject in as much detail as he could have wished, but it occurred to him that if he went part of the way, and set the ball rolling, other people would probably be able to carry it further. The Paper showed that a conversion could be readily done, and it was left to other people to make further suggestions of different ways of carrying it out. Mr. Livens had given particulars of an engine that had been constructed and the very good work it had done, and it was impossible for him to add to what Mr. Livens had said in that respect.

Mr. Tookey had referred to the question of town gas which was mentioned in the Paper. Members were probably aware that, during the last two or three years, the use of town gas for large power stations had been very seriously considered—not town gas as was understood by the ordinary buyer, but as understood by the large station engineer. Town gas when made in continuous vertical retorts could be put into the holder at a cost of about 4*d.* per 1,000 cubic feet, and at such a figure it became almost a better proposition to use town gas than to use producer-gas. It was an interesting fact that anything below 6*d.* per 1,000 cubic feet was, he believed, cheaper than the lowest steam-turbine figure. If an engine that could use town gas could be readily changed over to use crude oil, not necessarily in the way shown in the Paper, then obviously it was greatly to the convenience of the station. An engineer might have a battery of engines which were exactly alike, except that he decided to run one or two of them with crude oil and the rest on town gas, and he fitted them in

either way according to the market price of the fuel or according to the load on the station.

Mr. Tookey next asked him a question about the use of the exhaust in coke-oven gas. Exhaust was used in coke-oven gas, but it was not the same proposition as in Dr. Clerk's two-stage engine. It was used in coke-oven gas simply to reduce its activity, and had so been used for many years. He thought he knew of the particular instance to which Mr. Tookey had referred, which was a much later trial of the proposition. Within his own experience it was used ten years ago by Mr. Ernst Körting in some of his early engines, and it was really a convenience more than anything else. It enabled an engine with a higher compression to use a very rich gas where normally the compression might have to be reduced.

He was sorry that M. Mathot had, in his brief study of the Paper, missed one of the important points. The engine on page 159, to which he had referred, was quite a small convertible engine, and as normally arranged it did not have a low consumption. It could, however, have been made to have a lower consumption if required, but as it had to be attended to by very unskilled labour, it was designed accordingly. It was simply mentioned in the Paper to indicate how one might begin with the proposition. That engine, which might have been of only 10 h.p., could be changed over by an ordinary man to run with practically any fuel that was available. The compression was only 90, and if it had been raised to 150 the fuel consumption would have dropped in that proportion. M. Mathot had asked him whether it was easier to change from oil to gas or vice versa. If the engine had not been built for conversion, it was probably rather easier to change from oil to gas, but it was difficult to say without seeing the engine. With a specially-built engine, the necessary conditions were studied for each particular part for each particular fuel, but that might not be so with an oil-engine, which might have been so specially built for using oil that it would be rather difficult to convert it.

He was next asked to what extent, that is, to what power, he thought it was possible to convert an engine. The engine shown in

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Fig. 13 (page 169) was one of Messrs. Ruston and Proctor's standard engines which would do 600 h.p., and it was really easier to convert than was depicted in the Paper. The engine was stated in Fig. 13 to be of 520 h.p., but it would give 600 h.p., and to convert it from oil to gas would take about three hours. The pistons were not changed. He had referred to Mr. Livens' remarks so often that he did not think it was necessary to deal with them further in his reply, as they explained themselves. Mr. Livens had really been helping him all along to make some of the points clearer, and he was very thankful that he had been kind enough to do so.

Mr. Petter had referred to the two-cycle engine. Personally, he regretted that time had not permitted him to go into that question in detail, because for many years he had been in favour of the two-cycle engine, and had been concerned in building probably the largest two-cycle engines in this country. He had referred to this engine in order that he should not be charged with omitting all reference to it. The main difficulty of dealing with the Bolinder type of engine was that, in the oil-engine, air was used in the crank-case acting as a pump, and in the gas-engine it was therefore necessary to use a combustible mixture which was rather objectionable. The other engine shown in Fig. 4 (page 162) was not the same type at all; it was a stepped-piston type, the idea of which was that the mixture was taken away out of the crank-case. Such an engine would run perfectly well for small powers, but for large powers it was advisable to split the gas and air, and to have separate supply-pumps on the side, one for the gas and the other for the air; and when the engine was changed over to oil they both delivered air. There was otherwise very little difference except in the change of the cylinder head; it had to be water-cooled in one case and not in the other.

With regard to the question that had been asked as to what he meant by small powers, it had been stated that a very much greater alteration seemed to be necessary to change over to gas, but he thought that misconception arose from the fact that there were two distinct engines shown in Fig. 4, and probably it would

have been better to adhere to the Bolinder type in both cases. It was really done to show the two types.

With regard to Figs. 7 and 8 (page 164), to which reference had also been made by Mr. Petter, he was afraid it was not quite clear that in the oil-engine the piston filled the end of the cylinder, and in the gas-engine there was a straight flat-ended piston. There was a great deal more clearance than appeared from the Figures. Mr. Gibson had offered him an order, which he was very sorry he could not accept, because he had not given the proposition any thought. It was not impracticable, but it was difficult to convert an engine that had been built for gas alone. If it were possible readily to convert any engine from one type to another, there would be less novelty in the subject than he had thought.

In reply to Mr. Horace Boot, who referred to the question of the reliability of the change over from oil to gas, he did not think any decrease or increase was obtained; the engine would run equally well on either. Mr. Boot proceeded to state that the effect of conversion would, he thought, be to reduce the price of the engines. People who spoke at Meetings, who were not makers of engines, generally thought that whatever was done would have the effect of reducing the price. He would be very much beholden to any member who would state publicly that the suggested method would justifiably increase the selling price. With regard to the consumption diagram on page 165, he had been asked why the engine was more efficient at 105 h.p. than at 130 h.p. From 105 to 120 was what might be called the normal running load of the engine, and it was necessary to arrange for the engine to run most economically at that load, and therefore to set the atomizer to run at that load. That was the reason the curve rose on both sides.

He did not quite follow Mr. Patchell's criticism; he did not object to the Paper being called a tabloid, for he had explained the limited time he had available, due to work occasioned by the War; still, he believed the "tabloid" monoplanes at the Front had proved themselves to be the best flying machines. He had already answered the question Mr. Patchell asked, that the thermal efficiencies were taken on the gas and not on the coal. It was

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quite easy for anybody to convert them back to shillings and get the first costs. He thought, as he was only dealing with an engine and not including anything else in it—that is, the producer—the best course to adopt was to put the values down for the engines alone, not including the producer. If he had had time he would have been very glad to amplify the Paper as Mr. Patchell suggested, but he had hoped that in the course of the discussion more suggestions would have been made of various ways of dealing with the question, and he was grateful to Mr. Longridge for the kind remarks he had made in that regard. He also asked Mr. Patchell if he would kindly invent another name in place of the unsuitable word "semi-Diesel." He could not understand why people insisted on using such a word. The engine that was called by that name was really the development of an English engine. It was originally a horizontal type of engine, the hot-bulb feature of which was gradually extended, and it was the evolution of the Akroyd engine. The extraordinary habit had grown up, however, of recent years of crediting everything to the Germans, and so they now even had to use a half-German name to denote a type of engine. He most strongly objected to such a proceeding, and he hoped Mr. Patchell would give them a good name in place of it. In connexion with this name, there was a tendency nowadays to use the expression "high compression," but the engine to which he referred was normally a compression engine with added heat.

Mr. Michael Longridge had asked him if he had thought of a better way of changing over from one type to another without removing the piston. He had done so, and after the Meeting that evening he thought many of the members, if they had not already done so, would begin to think of ways for themselves. There was no doubt that the problem could be solved in a simpler form than was indicated in the Paper, but the idea of the Paper was to show how it could be done as things existed at present, without any material alteration in the form of any of the parts. An engine that was specially designed could, with their present experience, be made so that it could be changed over very readily from one type to the other in a very short time. The small engine that

Mr. Longridge thought would be useful for country places had been specially designed for that purpose, the idea being that it was possible for such an engine to run with practically any fuel that was ordinarily available in any country. As it was a small engine, the cost of the extra parts was very small indeed, and if they were not actually bought, they could be carried in stock, as the parts were strictly interchangeable, so that the machine could be run on coal, oil, wood, or any fuel that was available.

In reply to Captain Sankey, he desired to say that normally the scantlings of the engine depended upon the compression pressure, because the pre-ignition pressure sprang from the compression pressure. If an oil-engine were considered as an ignition engine in the way that a gas-engine was considered, it would have a higher pre-ignition pressure, and for that reason it was necessary to build it heavier. On the other hand, the type of oil-engine to which he referred did not work purely on the ignition cycle; it was a combination of the ignition and the constant pressure, so that normally a higher maximum pressure was not obtained than was the case with a gas-engine. If occasionally, however, at great intervals a pressure was registered that was higher than the gas-engine, it was taken care of by the ample factor of safety it was necessary to use. There was perhaps a tendency for the oil-engine to be rather heavier for that reason.

Discussion in Birmingham.

The CHAIRMAN (Mr. E. C. R. Marks) said that Mr. Chorlton had done much pioneer work in various directions, and, in particular, with the gas-engine. It was regrettable that he did not go on further with his work on large gas-engines, to which his attention was directed some few years ago. When they remembered that they could obtain with a gas-engine or an oil-engine up to 42 per cent.

(The Chairman.)

thermal efficiency, it made some of them who were responsible for the selling of electric energy, for cost price or somewhat less, as they did in Birmingham, wish that Mr. Chorlton had gone on with the large gas-engine problem, and had shown them how to get an efficiency of that sort instead of doing the poor best they could with steam-turbines, which now held the field. With steam turbo-generators they were not able to do better than about 17 per cent. efficiency from coal to electricity. He (Mr. Marks) felt it was only with internal-combustion engines that the fuel problem of this country was to be solved. He was constantly reminding his friends in the Birmingham Gas Department that they could nearly afford to give the gas away, because they got the price of their coal back in normal years from their residuals; whereas, in the production of electricity, the coal was burned to destruction, and with it most valuable substances which might be saved if they worked with gas-engines or with gas-driven generators of some kind rather than with steam-turbines.

At the top of page 156 of the Paper there was a very slight reference to the working of an engine with solid fuel. They knew that attempts had been made in that direction. Instead of drawing gas or liquid fuel into the cylinder or combustion chamber, solid fuel was drawn in, and one could imagine the state of the cylinder after a short time. Although many attempts had been made to use solid fuel, nothing had come of it yet.

It was news to him that there was a definite demand for an engine to work either with oil or with gas. One knew it had been done as a temporary measure, and Mr. Chorlton mentioned that the agricultural labourer would be able to make the change. A little later he told them the demand was chiefly on the Continent, or abroad. One would be a little sorry for the agricultural labourer who had to change the engine quickly from gas to oil. As to the arrangement shown in Fig. 2 (page 157), he gathered from the Paper that many of those engines had been made, and they were told, on page 159, that the engine was lately built with success. There were varying degrees of success; but the author pointed out that it was really the beginning, and would lead to something better.

Coming to the engine which the author favoured—the engine in which they got a higher compression when working with oil than when working with gas—one of the modifications involved the taking off of one piston and substituting another. That did not strike one as being a final solution of the problem. The author had pointed out that they got lower temperatures with gas than with oil, and he (Mr. Marks) gathered that the engine was built with the higher temperatures in view; that was to say, the engine which might work very well with the comparatively moderate temperatures existing with the gas fuel, might give them trouble with the higher temperatures involved when they converted it for oil fuel. He thought that the author did not favour very much the semi-Diesel type of engine in which the oil was ejected on to a hot surface; yet, as far as the smaller sizes were concerned, it was a popular engine to-day. A considerable number were made, and they worked very satisfactorily.

The suggestion to use super-compression (introduced by Dr. Dugald Clerk) when they were running as a gas-engine, for the sake of keeping their temperatures down, and then to cut out the super-compression when they were working with oil, was attractive and promising.

Mr. A. G. HAFFENDEN said it was a great surprise to him to learn from the Paper that engines had actually been constructed and sold as convertible engines. Although the author stated that the conversion was a simple matter, and could be done by any farm hand, it seemed to him that it involved a considerable amount of work, and could not be done in a few minutes. The only adequate reason that he could imagine, to justify the installation of an engine that was particularly equipped for conversion from one kind of fuel to another, would be to meet emergencies that might arise at short notice. If an engine to meet those conditions required a large amount of work, its value was considerably depreciated. For instance, if they referred to the diagrams of the engine on page 164, the main alteration involved, apparently, was the change of piston, which was a large undertaking on an engine of 1,000 h.p. He

(Mr. A. G. Haffenden.)

thought Mr. Chorlton suggested it could be used to any power up to that size. A 1,000-h.p. engine would have several cylinders, and they had an equal number of pistons to take out and replace. The change of the back-end plate was a small matter, and there also seemed to be a change in the inlet-valve, which might not be an essential. The idea might be developed further, and the necessary change could be obtained by alteration in the design of the combustion-chamber, in order to dispense with the necessity of changing the piston. Apart from that, he did not think that there was any great scope for the proposal—at any rate, not in England. As the author himself had pointed out, the British buyer of machinery always wanted simplicity, and the man who offered a complicated engine as a rule was not in the running at all. If the type of engine in question was to be of practical use, it was essential that it should be simple and that the change should be made with the minimum of labour. It might be worth while developing the idea with that point in view—that was to say, to modify the construction of the combustion-chamber, or cylinder-head, to obviate the necessity of changing the piston.

Mr. A. E. A. Edwards observed that the author had introduced a subject which was more or less new to many present. It would no doubt prove the basis for very much experiment at the University, where they, perhaps, had more time to follow up such investigations than Mr. Chorlton had. The author had told them about the possibilities of the engine, but he had not said anything about the commercial prospects. Nobody would buy an engine to run on gas one day and oil the next, and therefore it was not the user who wanted an engine of that class. It was the branch establishments of the makers and the foreign merchants who stocked engines to whom that class of engine would appeal, and it was to them that Mr. Chorlton would have to look for his business. It would be very useful to be able to have one engine in stock and offer to sell it either as an oil or as a gas engine. But if one wanted to sell it as an oil-engine, they all knew the engine required adjustment even for different grades of oil; if they changed from Royal Daylight to

Russian oil, an adjustment had to be made, the compression altered, and so on. The foreign merchant would therefore require to know something about the class of oil before he would attempt to sell an engine to work with oil.

Gas-engine builders, to his mind, had run too much on "standard" lines. If anyone wanted a gas-engine, he could get one with a fly-wheel on the left and an outer bearing and a pulley outside that. But if he wanted any alteration, the makers would not do it, and his only remedy was to buy a steam-engine. The gas-engine makers would make no alteration to standard, and the user must buy an engine as it was, or leave it alone. On the other hand, one could obtain a steam-engine to do 20 revolutions or 1,000 a minute. But with gas-engines and oil-engines the makers had not adapted themselves to the necessities of what users would like, although gas and oil engines in themselves, it seemed to him, lent themselves to almost equal modifications. For instance, an ordinary commercial gas-engine weighed something like 200 lb. per h.p., while a motor-car engine weighed about 4 lb. per h.p., and one could obtain an aeroplane engine which weighed even less. In between the ordinary commercial gas-engine and a motor-car engine there seemed to be a field for development. The ordinary factory manager wanted an engine to which he could attend without calling in an engineer. He probably had a motor-car of his own, and if anything went wrong with it, he could doubtless attend to it, because the parts were so light he could handle them. But if anything went wrong with the engine in the factory, his men could not attend to it, because it was so heavy they could not tackle it. If factory engines were built running faster than the ordinary engine but much lighter, so that the change of piston or anything of that sort could be carried out by hand without any tackle, adjustments from oil to gas would be very much more readily done than they would be in large engines. Of course, it might be said that a motor-car engine had no length of life in it, but, as a matter of fact, it had a fair length of life. A motor-car engine would do 10,000 miles conveniently enough without taking down at all. He had known a Daimler engine run as many as 30,000 miles

(Mr. A. E. A. Edwards.)
without taking down, which would be equal to about three years' work on an ordinary factory engine. If an engine would run that length of time without taking down, they could not say that it would require any very large amount of attention; and so an engine of the lighter type seemed to lend itself to factory purposes. They could put one where they liked on an upper floor, and there was not the trouble in handling them that there was with the large ones.

The author had not mentioned anything with regard to the alteration in the governing which was necessary. The governing of a gas-engine was now, he supposed, usually regulated by the lift of the inlet-valve so as to govern the mixture of gas and air. That method would be quite out of the question with an oil-engine where they had to regulate the amount of oil injected. If that point were cleared up it would be an advantage.

Mr. Chorlton had not mentioned the well-known class of oil-engine in which the charge was ignited by a spark, like the gas-engine charge. This engine had neither a hot bulb nor high compression. He would be glad to have the author's opinion as to whether this type would not be the best to make for conversion from oil to gas. It would not be so economical as the high-compression oil-engines which the author had described, as they could only make use of refined petroleum; but, after all, what a manufacturer required was ease and convenience and reliability far more than economy in fuel.

Mr. W. A. Jeboult remarked that the Paper struck him as a particularly useful one for a manufacturing engineer. The particular design which the author preferred appealed to the speaker very strongly, and it looked to him a nice arrangement that the various parts could be kept in stock, which would be quite suitable for either a gas-engine or an oil-engine. He would not like an agricultural labourer to do the job of converting, because it would be rather difficult for him to attempt to remove the heads which were held on by set-screws inside the water space. The question of the governing which Mr. Edwards raised was a most

important one, and he would be glad to know how that was to be got over on a convertible engine.

Mr. A. GOLDIE ENGHOLM said that, from the commercial point of view, he would like to know if the author could give any information with regard to the prices of convertible engines compared with the ordinary standard types of gas or oil engines, as he thought that the first capital outlay, as well as cost of running, was a very important factor for users.

Mr. A. JOHNSON (Birmingham) stated that there seemed to be considerable scope for an engine, like the one suggested by the author, in large agricultural districts, such as were found in Canada and Russia. The farmers joined together, or perhaps a company was formed, for the purpose of getting the grain in, and threshing it on the field, afterwards carting the semi-finished product to granaries and disposing of the straw at the base. If a company carried out this work, it was quite possible that the district was only capable of supplying a heavy kind of fuel, while at the next base of operation a totally different grade could be supplied. An engine, therefore, designed on the lines put forward would enable this work to be carried out economically and expeditiously.

Supposing one had to operate a very large electrical system, where constant output was of utmost importance and where the prime mover units were of this class of engine, what steps would be adopted for ensuring that a constant shaft horse-power, and consequently constant kilowatt output at the terminals of the generator, would be delivered? For example, a generator delivering 500 kw. would require a shaft horse-power at the engine of approximately 730 b.h.p. If the engine were capable of delivering this power when running from one grade of fuel, it was assumed that when changed over to a lower grade fuel, the power would not be the same, and the speaker would be interested to hear of the probable steps taken to ensure the maintenance of output.

Mr. W. H. THORNBERY said that the subject of the Paper was of no practical importance to those in Birmingham, because there were comparatively few oil-engines installed. Most of the internal-combustion engines used in Birmingham were gas-engines, and he thought that the question of an engine which might be driven either by oil or by gas would be a purely academic one in that district, although he was given to understand that in certain districts abroad it was a very important question. The subject was of great interest to manufacturing engineers in this country who exported engines to districts where either oil or gas might be used. It affected at present a large amount of trade, and would do so more in the future.

Mr. JOHN A. LONES (University of Birmingham) thanked the Council of the Institution for extending an invitation to the Students of the Engineering Society to attend the Meeting. They had very little opportunity of studying the subject of oil-engines, and the Paper had therefore been very instructive.

Mr. OSWALD B. DAVIES (Coventry) said he thought there was a great opportunity for the development in this country of the ideas mentioned in the Paper. He had come from Coventry to hear the Paper, and he had been struck with the developments in the use of petrol and paraffin. Many of his friends had been trying to use paraffin on their cars and bicycles, and they had experienced a certain amount of difficulty. It would be a good thing if they could convert an engine to run from petrol to paraffin on the principle laid down in the Paper.

Mr. CHORLTON, in reply to the discussion, said he knew Mr. Marks had had a great difficulty in getting people to agree with his power station problems, particularly when driven by town gas. Town gas, when generated in modern ways, in coke-ovens, or vertically continuous retorts, could be put into the holder at a very low figure, say, 4*d.* per thousand cubic feet. Anything under 6*d.* per thousand for town gas used in a gas-engine produced

cheaper power than any steam-turbine. It was possible to use solid fuel in the Humphrey pump, but the difficulty was not with the piston or the cylinder lining, but rather with the injection device.

There were sundry remarks by different speakers made about the agricultural labourer mentioned in the Paper. But the agricultural labourer was only mentioned on page 159, and yet various critics would carry him through to the end of the Paper. He was only supposed to deal with a very small engine which would probably go on a table, so that it was not a difficult job to change over. He ventured to think that this changing over had not been quite appreciated by various speakers. To Mr. Thornbery he would reply that if the coal in his district gradually went up in price, as it seemed to be doing, they would surely come to using oil at 42*s*. 6*d*., a figure at which they could buy Mexican oil that day. The proposition was therefore worth thinking about, even in Birmingham.

In regard to the criticism of the particular forms of the engine, he had commenced by saying that his Paper was written when he had but little time to spare, and consequently he could not go into all the different ways of change; it was a suggestion, and it should naturally occur to them that the idea could be carried out in different ways. He was sorry personally that more manufacturers had not spoken. There was in this country, he regretted to say, a great reluctance on the part of manufacturers to speak about the things they made.

Mr. Haffenden referred (page 189) to the change of piston in 1,000-h.p. engines. On page 165 was shown one way of doing it, not necessarily all the ways, and it did not follow that in a 1,000-h.p. engine the piston should be changed.

Mr. Edwards referred to the high-speed engine versus the low-speed engine. The ordinary motor-car engine weighed probably 40 lb. per b.h.p., and the gas-engine probably up to 200 lb. per b.h.p. There was no doubt that any discussion on the question of weights per horse-power was very interesting; but there were difficulties in using a high-speed engine for ordinary purposes.

(Mr. Chorlton.)

First, it was more difficult to follow if it went wrong; and second, its apparent life and success were due to the fact that the ordinary motor-engine did not run at anything like continuous full load, whilst the ordinary horizontal slow-speed engine did. They would find that these were really the important differences. When they came to hard work, they must depart from the motor-engine type in consequence.

Mr. Jeboult said he thought the design was convenient for the manufacturer. It was so in some ways, but not necessarily. Any reasonable manufacturer designed with a view to convenience in stocking and in manufacturing. The arrangement under discussion was brought forward as a commercial problem for the convenience of the buyer who might desire, by reason of the rise in price of one fuel and the fall in price of another, to change over. In reply to Mr. Engholm, he (the author) did not see that the price entered into the problem of conversion. He thought it would be useful in any agricultural district where, of course, fuel was more difficult to obtain, and where, if one ran out of oil, one could use another fuel. It was suggested in the previous week that it would be quite convenient and a good proposition if a man desired to put down a gas-engine but had not enough capital. He might, however, install an oil-engine first, and later he might add a producer and thus convert it into a gas-engine.

Mr. Davies mentioned the convenience of going over from petrol to paraffin by reducing the compression. There was no doubt it would eventually be done, although for commercial motor work it would not be carried out quite in the same way they were doing it now.

Mr. Edwards asked whether Mr. Chorlton had made any experiments with an oil-engine, in which the charge was ignited in the same way as in a gas-engine, by electric spark, and whether that would not be easier to convert from oil to gas.

Mr. Chorlton said he could not answer that immediately, because there were several ways of doing it. If they were using a comparatively light oil which they could admit on the suction

stroke—a carburetted oil especially—they could, by making the bulb smaller (that is, uncooled surface), run electrically all the time. But if it were an ordinary gas-engine, water-cooled throughout, good paraffin was about all they could use, and then they must heat it very considerably before it was admitted to the cylinder. If crude oil were used, it would be almost impossible. It would have to be injected at the end of the stroke, and then there was not the compression to ignite it. An ignition oil with electrical initial spark might, however, be used.

Discussion in Manchester.

In the unavoidable absence of Mr. MICHAEL LONGRIDGE, *Vice-President*, the Chair was taken by Mr. DANIEL ADAMSON, who expressed his regret, in which he was sure the Meeting would join, that doctor's orders prevented Mr. Longridge from attending and presiding as a Vice-President of the Institution at this first Meeting in the Engineers' Club of Manchester.

He also expressed his feeling of gratification that the first Paper to be read under these circumstances should be by Mr. Chorlton, a Life Member of the Club, who had taken a very active part in its inauguration before leaving the district.

The CHAIRMAN (Mr. Daniel Adamson) said the Meeting was partly the result of Mr. Chorlton's own efforts of about three years ago, when he took an active part in expressing the feeling of local members that more might be done for them by the Institution. Mr. Chorlton had read the Paper to-night for the third time in the course of the last seven days. With those facts before them, the members would unite in thanking him heartily for his Paper, and show their approval in the usual way.

The vote of thanks was adopted unanimously.

The CHAIRMAN opened the discussion by pointing out the importance of the subject to engineers in Manchester, the home of the successful manufacture of the Otto gas-engine, and later of the Diesel oil-engine.

Mr. G. E. WINDELER (Stockport) said that Manchester was the home of the internal-combustion engine, and it was fitting that they should have the opportunity of discussing any new principles or features which engineers had to put forward. Food for thought had certainly been given to the builders of small gas and oil engines who had to go in for intensive production on a large scale, and who had very often to deal with varying conditions in the territories where similar sized engines had to work on different kinds of fuel. It would be of particular value if the parts of such engines could be made interchangeable for different kinds of fuel. That problem concerned the manufacturing side of the industry. To others the economy of the engines was the more important point, and he was sure Mr. Chorlton's remarks in that connexion had been followed with great interest.

During the last two years there had been considerable progress made with small oil-engines, in regard to the use of cheaper grades of fuel and improved economy. It was said the fuel consumption per b.h.p. hour on such engines had been as low as 0·45 lb. when using heavy oils, and in some cases residual oils. These results, he believed, had been obtained on the higher compression engines, but he had not had any opportunity of seeing results obtained from the lower compression engine. Personally he was interested in the Diesel engine, and naturally thought it was the best—in fact he knew it was. Certainly the fuel consumption obtained with it was the very best that had yet been known on any heat engine; it was as low as 0·61 lb. of fuel oil per kw. hour. But the Diesel engine was essentially an engine for the larger powers, and the small ordinary oil-engine using heavy oils had undoubtedly met a long-felt want in providing a more economical prime-mover for the lower powers.

The author referred to the conversion of the Diesel engine to the gas-engine as not being a commercial proposition. During a

recent visit to Germany—it was before 4th August 1914—he was in what he thought were the largest works there that went in for extensive production of gas-engines, oil-engines, napthalene engines and spirit engines. There he saw working side by side Diesel engines and gas-engines of precisely the same design, and working with exactly the same main parts, the only difference being that the fuel-valve had been removed from the breech-end and an ignition arrangement fitted. A certain modification would of course be made to the gas and air valve, and the air-compressor would be removed. The parts of the engine had been specially designed to admit of its convertibility from a Diesel engine to a gas-engine. The compression for the Diesel engine cycle was produced by introducing a distance-piece between the top end of the connecting-rod and the brasses, thus reducing the compression space. The engine worked smoothly and efficiently, both as a gas and as an oil engine, and the firm considered that they had a sound commercial proposition. He could not vouch for this, but could only tell the members what he himself had heard and seen; there were however a considerable number of these engines going through. They were certainly not big powers, but were convertible, working smoothly and efficiently. He was not sure that the convertibility was carried out by farm hands, as was instanced on Mr. Chorlton's engine, but he was sure that the modification was made quite easily.

With regard to the utilization of varying qualities and kinds of fuel, he thought the Diesel engine held the field. At his company's works, coke-oven tar had been utilized quite successfully. The engine worked economically, smoothly, and cleanly on that product. This opened up a new field for the Diesel engines in times when, as Mr. Chorlton stated, we might be in difficulties for want of fuel, because there was produced in this country a great quantity of coke-oven tar, which was available for use in this way. The modification to the engine which made it possible to employ this fuel was a great advantage, and was quite a simple apparatus and easily adaptable to engines of his firm's design.

He was sorry he could not add any remarks about Dr. Dugald Clerk's engine; he had followed with much interest Mr. Chorlton's

(Mr. G. E. Windeler.)
account, and it was evidently one to which careful thought should be given. The conversion of engines from one fuel to another was of special importance in Germany and other countries where all grades of fuel were comparatively expensive, compared with the conditions ruling in this country. Therefore the Germans had studied the subject much more carefully and in a very able manner. They had thus made progress and got abreast of the English makers in many ways. Whilst our friends were fighting at the Front, those who remained at home had to deal with these problems, and he thought many firms would come into their own in connexion with internal-combustion engines. A short time ago they heard that the National Gas Engine Company had obtained a very large order for high powered gas-engines, and he believed Messrs. Galloways also had participated in a similar contract. It was very gratifying to know that Manchester was holding its own in this direction, and he was sure it would continue to do so.

Mr. Joseph Butterworth said it was about thirty years since he was actively engaged in the manufacture of gas-engines, but he had always maintained an interest (somewhat academic, no doubt) in the subject. At first sight the Paper might seem useless in some respects, because it was absolutely impossible to make a convertible engine that should be the most economical for both oil and gas; they must sacrifice in one direction or the other. But of all commodities oil was the most likely to be cornered, and in the past it had been cornered most effectively in many countries. To take one instance. When the Diesel engine started, the price of crude oils was rushed up. There was comparatively no use for them previously, but directly it was seen that the engine was a commercial proposition to use for power, prices rose rapidly. That would be accentuated in the future as oil came more and more into use for power purposes. Hence the necessity for engines of this type and the useful purpose which was served by Mr. Chorlton bringing the subject before them.

The only point that he wished to criticize in the Paper was with regard to heating the gas before it was put into the cylinders.

His experience was that wherever that was done, the M.E.P. was reduced, with the result that they did not get the same horse-power per weight of engine or per cost of engine, and that, of course, condemned it as a commercial proposition. In his opinion there was a far better method. Seeing that there were so many methods of ignition, it was much better to compress the air first and even cool it by means of intermediate cooling before it was introduced into the cylinder. For example, suppose they had a rotary compressor of any well-known type. Only one additional working part was introduced, but if they compressed up to 3 lb. pressure and admitted the air first, they subsequently got an absolute pressure of, say, 18 against 15. When they came to calculate that, taking into consideration the cooling, they would find the effect was to raise the compression pressure from 150 lb. to nearly 200 lb., which brought it within the range as a fairly commercial oil-engine.

Mr. H. N. BICKERTON said he was closely associated with Dr. Dugald Clerk, whose name had been mentioned in the course of the evening, and perhaps the members would like to hear what his opinion was of the suggested use made by the author of the super-compression engine. He (Mr. Bickerton) saw Dr. Clerk last week, who mentioned that the Paper was to be read in London, and that he should attend the Meeting. It must have been a great disappointment to Dr. Clerk that he was not able to be present.

The author suggested that the super-compression engine might be a means of raising the compression. That was not quite Dr. Clerk's idea when he suggested super-compression; his object was to add to the volume of the charge in the cylinder, and thereby increase the charge. In the engines which were made, it was very successful, and the only objection was that it necessitated further mechanical contrivances; of course, it was a matter for consideration whether, in small engines, the result justified the extra complication, the extra expense, and the extra weight involved. But there was another method of super-

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compression which was more favourable, and which Dr. Clerk carried out successfully—experimentally. That was super-compression by exhaust gases. He bottled up some of the exhaust gases at the end of the power stroke before allowing them to escape from the cylinder to the atmosphere; having retained them under considerable pressure, he cooled them and introduced them into the cylinder, after the latter had been fully charged by the suction stroke of the engine and the inlet-valve closed in the ordinary way. That was a much simpler method and much less expensive to carry out, and it did not involve a great amount of complication.

The author suggested that in an oil-engine the object to be attained—of course, it was the object in dealing with crude oils and semi-crude oils—was to raise the compression by a simple alteration and by the method of ignition. Whether the compression could be raised in that manner sufficiently, he did not know. In fact he would like to have the author's opinion whether it would not be better to introduce the bottled-up exhaust gases in a hot state. Then they would not only raise the compression, but they would also heat the charge, which would be an advantage in an oil-engine of that description. Of course, it would be quite correct to say that, if they heated the incoming charge of an internal-combustion engine before or during admission, they diminished its efficiency, but the reply was that they would not heat the incoming charge—they would first introduce a charge as cool as the atmosphere and heat it afterwards when it was enclosed in the cylinder. He did not think they would lose any efficiency in that way. In fact he rather expected they would improve it.

The engine which the author suggested as a crude-oil engine, he could not accept as such. It was certainly an engine which would work with heavier oils than the ordinary paraffin engine, but it was quite unfair to compare it with the Diesel engine. The difference between the two was simply this, that in the crude-oil engine suggested by Mr. Chorlton, one had to be very careful in selecting the oils for good working, but the Diesel engine could work well with any oil of a fuel character.

Mr. Frank Foster said he would like to suggest to the author that he had omitted one important conversion of the combustion engine, namely to steam working. It might seem rather outside the scope of the Paper, but as a matter of fact a great many gas and oil engines in this country were situated in places where steam was always available. It was quite possible for gas-engines, particularly of the two-cycle type, to be converted to steam. Some members might think the conversion of gas and oil engines was not a very practical suggestion. He happened to know that it was done to a considerable extent outside this country. Some time ago a Continental firm asked him to obtain particulars of a convertible engine of English make on the ground that it was found to be a competitor of their Diesel engine in Russia. He did not think it was quite right to obtain the particulars, and he did not forward them, but the incident was interesting as showing that conversion was an important commercial matter.

He was rather disappointed that the author said little about the mechanical features involved in the change over. The fact that the gas-engine was substantially the same thing as the oil-engine in its main working parts and general cycle of operations had been known for thirty, or more, years. The problems of the conversion were primarily mechanical ones. Although they were indebted to Mr. Chorlton for what they might call the analysis of the general conditions, their debt would have been greater if he had dealt with the mechanical problems involved. The difficulty presented by the air-compressor on self-igniting oil-engines was mentioned in the Paper. He thought that difficulty could be removed, because he knew that some Diesel engines were at work in this country without compressed air for oil injection. He had had some experience of that class of fuel injector, and knew that many difficult problems arose. It was possible to solve them, and the main line of progress lay in having ample pressure—not a few hundred pounds per square inch, but several thousands—with jets fine enough, and proper oil filtration. All dirt should be kept away. There was dirt even after they had passed it through ordinary filters. By that means they could get a spray so fine that it was

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barely moist to the hand. The spray burned without smoke, which was a proof that it was sprayed as finely as they required it in an oil-engine. If they could spray oil without compressed air—and undoubtedly they could—one of the difficulties of conversion was removed.

He knew very little about the Clerk super-compression engine, and therefore would not speak of it, but there were other engines not altogether dissimilar in aim, to which he might refer. The use of scavenging had been long known in this country through the Premier gas-engine, and up to a certain point it was a success. On the Continent the two-cycle engines also used scavenging, and several firms had endeavoured to develop the four-cycle scavenging engines. There was, to his mind, a radical difference between their aims. In the two-cycle they scavenged because they must blow the gases out, in order to take in a fresh charge. In the four-cycle they scavenged for something entirely different. First of all, they scavenged to blow the waste gases or the burnt products out of the clearance space. That in itself had this effect, that at the end of the suction stroke the gas-engine contained a charge full of gas and air, which was useful, and burnt products, which were useless, from the point of view of developing power. By blowing out the burnt products before commencing the suction stroke, a greater weight of charge was obtained, and therefore a greater M.E.P. By reducing the compression pressure so that they did not get a higher total pressure, they obtained a higher power from a given gas-engine, and therefore the capital costs were kept down. Undoubtedly the greatest obstacle in the way of the gas and oil engines to-day was capital cost and not any question of fuel efficiency, nor even of reliability. The scavenging in the four-cycle system was pushed to this further point. Not only did they sweep out the burnt products in the clearance space, but they did it at the instant when the piston was at the compression end of its stroke, and when there were exposed to the scavenging air only the piston face and the combustion chamber of the engine—the two parts which were most heated and were most in need of cooling. In this way the walls were cooled and the ability to advance to higher temperatures

and develop more power was obtained. Moreover, the whole of the gas during the charging stroke was supplied under steady pressure, so that at the end of the suction stroke, instead of having the total gas in the charge (whatever it might be composed of) at a pressure less than atmospheric, the pressure was slightly above atmospheric. That system was introduced, he thought, by Messrs. Ehrhardt and Sehmer, in Germany. It was being developed in this country by Galloways, Ltd., and it had been copied with certain modifications by other firms on the Continent. The results in practice had justified expectations up to a certain point. For instance, there were engines in this country and on the Continent which now developed regularly from 35 to 40 per cent. more power (at the same speed) than they did before under the old system. While it was obvious that that meant a very great gain under certain conditions, it did not pay, as a general rule, to do it with one engine alone. The advantages were felt where there were a number of engines in a power-station. In that case it was a great advantage to have relatively few engines, and this scavenging system enabled them to go up to 35 or 40 per cent. overload without the slightest fear, because they did not get a greater pressure or temperature in the cylinder, although they went up to 35 per cent. higher M.E.P. Also, they got a higher mechanical efficiency because the suction losses were avoided. Moreover, the engines had a much flatter consumption-curve than before, with the result that the range of economy was far greater than in the ordinary engine. The limited range of economy was one of the drawbacks of the ordinary four-cycle gas-engine. He had referred to this question of scavenging because it seemed to have some bearing upon the super-compression system which Mr. Chorlton and Mr. Bickerton had mentioned.

He would like to make a few further remarks upon the change over from oil to gas, and vice versa. Personally, he was not commercially interested in the small engine, and in the large engine one did not come across the question of using oil or gas very much. But they were faced more with the question of using different qualities of gas. For instance, at many ironworks they

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had coke-oven gas and blast-furnace gas, the one about 400 to 450 B.Th.U. and the other about 90 to 100. An engine could be run without change of valve-gear upon either of those gases, but the results were not altogether satisfactory if maximum economy were wanted. It was all right for a temporary change-over, but to obtain the maximum economy one had to alter the valve details, such as the inner valve-box and the air and gas distributing arrangements. If that were done there was no difficulty about it, except the change of compression. Among the small-engine makers there seemed to be a good deal of hesitancy about the changing of the compression, and he did not know why that should be. In the larger engine it was a very simple matter. For instance, instead of making a joint on the flange, it was made on a shoulder in the cylinder. By turning that shoulder down more, they could reduce the compression; by putting in a ring they could increase it. It could be done very rapidly without any change of the other mechanical parts of the engine. He did not know why that system should not be adopted upon smaller engines, as it would avoid such devices as plates on the connecting-rod end, which he thought was a wrong method, as the piston then altered as to the part of the cylinder on which it ran, and ridges were formed by the ring. In that way they contravened at one time or another one of the great rules of engine design, that the piston-ring should just run to the edge of the bell mouth, no farther and no less. He put that forward as an example of the problems which arose when they came to change over.

Mr. ALFRED SAXON said the author had brought before them a problem that was interesting to engineers even outside the ranks of those connected with the combustion engine. Although the experimental stage had been passed, the engine had only been made up to a certain size, and its possibilities and limitations would be determined under actual working conditions and with larger sizes. Mr. Chorlton gave something away in his Paper and naturally expected to get something in return. To judge from his own remarks, he wished to obtain information as to how to advance a

step further towards the convertibility of gas and oil engines of the large sizes. At the bottom of page 156 he said it might be taken generally that the degree of compression was the governing factor. He was quite right in that statement. On page 163 he remarked, "The possibilities of this type of convertible engine appear, from these indications, to be very great; and an engine which has at present been made in considerable numbers to fulfil these conditions is shown in Figs. 6 to 8." There could be no question, judging from other evidence which had been given that evening, that the author's firm had made those engines up to a certain size. He (Mr. Saxon) would like to know what that size was. Further, what was the size of the gas or oil engines which they had been able to make convertible? Fig. 13 (page 169) was a diagram of a four-cycle 520 b.h.p. oil-engine, but it was not stated whether that was the limit upon which tests had been made.

In his concluding remarks the author said he had come to the conclusion that, for powers up to, say, 1,000 b.h.p., the type of engine represented by the Ruston Class B was the most suitable as a convertible engine. Had the author's firm made such an engine, or was he asking for information? Mr. Chorlton knew something of the difficulties of the large gas-engine, and he would realize they were already sufficiently great without the further handicap of this question of convertibility. The existence of such difficulties was clearly shown by the reports of firms who had in hand the manufacture of large gas-engines; there were, for instance, as Mr. Foster suggested, the variations of the gas and the stuff that came along with the gas. Bearing those points in mind, it was to be anticipated that any step towards the sweeping change of making the engines convertible would be taken very carefully indeed.

Mr. CHORLTON, in replying to the discussion, said that Mr. Windeler had told them of similar gas and oil (Diesel) engines of a well-known type (he thought, Deutz) working side by side in Germany. He himself had seen a similar couple; they were built to use the same common parts, but were not convertible engines

(Mr. Chorlton.)

in the sense he meant it. What the stresses were in the Diesel engine of the pair he did not know, but judging by the appearance, the stresses would be higher than in the gas-engine. If it was the Deutz, he thought he was right in saying it was of the direct injection type without the use of air-bottles, and that in consequence the initial cylinder-pressures were higher. The engines he had seen appeared to be working well, but at what load he could not say.

Mr. Windeler also referred to the use of coke-oven tar, which could be used in the Diesel engine successfully. But was it not a question of height of temperature? Therefore he did not see why the argument was brought forward that it could not be used in other engines than those described in the Paper. These engines also did not require special oils. The Ruston engine had run on most of the oils that had been submitted for trial; it had also run successfully on the ordinary oils submitted in general practice, even without going to a higher degree of compression than was given in the Paper. As the compression was raised, it became easier to use heavy oils, or perhaps it was better to say that the result was effected in a rather different way. Undoubtedly the ability to use tar-oil was a considerable advantage, for it increased the range of fuels available, by adding a fuel which was outside the power of oil combines. At the present time oil was very high in price as generally understood, but the Anglo-Mexican was sold at about 42*s.* 6*d.* per ton, and the fact that it was in competition with the Standard Oil Trust ought to help to bring these prices down. Mexican oil could be readily used in the Ruston engine described.

Mr. Butterworth stated that there did not seem to be anything of commercial value in the proposition in the Paper. He (the author) thought there was. As he had said at the beginning, he did not want to suggest that the subject had been completely gone through in the Paper, but he wished to furnish an opportunity for others to help with suggestions during the discussion. The rotary compressor suggested by Mr. Butterworth was not strictly germane to the subject of the Paper; it introduced an entirely different type of machine. As ordinarily understood, it was not an efficient

contrivance for working in connexion with gas-engines in the way suggested. When it was used (as Mr. Foster described later) to supply a supercharge or scavenge charge to a large power-station, it became a different proposition, which could then be dealt with in a different and probably more economical way. But when the question was how to deal with an individual engine and convert it from one fuel to another, it was not a way that ought to be considered.

He was very glad that Mr. Bickerton had told them something about Dr. Clerk's engine. It was quite true that Dr. Clerk's idea was to increase the charge in the cylinder; still, his particular way of dealing with it was designed to get over the very high maximum temperature which such a heavy charge would otherwise involve. For the purpose of making that a little clearer in regard to the conversion problem, he considered it as a two-stroke compression and less as an extra charge which was added at the end of the stroke. The use of the inert gases, that is to say exhaust gases, in the way suggested by Mr. Bickerton was good. The ordinary two-cycle crank-case charging engine, which they all knew had been used a great deal for the ordinary classes of fuel-oil, really worked somewhat upon that principle, not with a material increase of the initial pressure of charging—that is, above atmosphere—yet it worked always with a large amount of exhaust gases left in the cylinder. The result was that there was a very much increased final temperature at the end of the stroke, so that one really secured in a modified way what Mr. Bickerton was suggesting, though the economy was lower, as it only worked at 150 lb. compression. It used added heat (exhaust) as well as a hot bulb at the cylinder end. There was no doubt that, speaking generally, the present waste of the exhaust of any internal-combustion engine was regrettable, and it ought to be made use of in some way. Very often the release pressure was about 40 lb. per square inch; with a super-compression engine it was about 60 lb., which was quite a material pressure and could be used either as pressure or as temperature.

Mr. Bickerton also mentioned the comparison between the Diesel engine and the oil-engine as described, in the use of fuel-oil.

(Mr. Chorlton.)

He quite understood Mr. Bickerton's point of view, and he thought that the complication of the Diesel engine needed some accounting for. It was a wonderful construction, but he did not think it was now in the form it would become eventually. Was he to understand that Mr. Foster suggested a convertible engine that would work with either gas or steam?

Mr. FOSTER: Yes.

Mr. CHORLTON said he held that idea originally. A two-cycle engine was essentially a uniflow engine, and when Stumpf brought out a uniflow engine in Germany he (Mr. Chorlton) thought that steam had been simply applied to a two-cycle gas-engine. Therefore the easiest thing for him to do would be to build a uniflow engine on the two-cycle principle in this country. That was before anybody here had taken up the idea which he obtained from the original German communications, but his firm did not think it was worth their while to do so. A steam-gas convertible engine could, he thought, be made without great difficulty, but the use of steam in the cylinder created a certain form of rubbing surface quite different from the surface of the cylinder created in a gas-engine, and he doubted whether for this reason they could take a gas-engine and turn it into a steam-engine with the same cylinder surface. The point had yet to be proved, and there was considerable doubt about it. The use of water in a gas-engine or an oil-engine, particularly if used in quantity, tended to create wear.

A further criticism was made that he had not gone far enough in the description of the mechanical features of the change from one type to another. He did not feel he was concerned to deal with every detail. He wanted to present the proposition in principle, and to bring forward what he believed was a commercial suggestion. As a matter of fact the mechanical features were nearly all described; the same governing was used, but a different attachment to the oil-pump or to the throttle-valve was necessary. Mr. Foster also dealt with the question of mechanical atomizing, which subject was always with them. In fuel-oils it had been

developed considerably of late years, and was becoming a very efficient way of dealing with them. In his opinion, this method would ultimately become the recognized way of solving the problem.

He quite agreed with Mr. Foster about the high capital cost of combustion engines, which had been the bane of all large internal-combustion engines. But he did not know that even the supercharging which was described, such as was used at Skinningrove, was going to help them materially out of the difficulty. It was more likely that the advance in the cost of every fuel that was used would make it essential for people to secure the highest efficiency at almost any reasonable first cost, and therefore, as the different fuels rose in price, the large gas-engine maker would eventually benefit; he certainly deserved it. He (Mr. Chorlton) had been trying for many years to surmount this difficulty, and there was now a great deal more hope for the large gas-engine as a commercial proposition than in the past. The method of altering the compression by moving the cylinder-cover was quite a good one; it could be used and had been used in these types of engines. It was one indication—he had thought more would have been given—of how to make the change of one compression to another.

Mr. Saxon had rather alarmed him by expressing a belief that he (the author) had given something away. An engineer connected with an important business had to be careful how he dealt with these problems; at the same time he might go far in reading a Paper dealing with principles without giving away anything that was of material value to his firm. In other words, if he only dealt with the principle of the idea, it would still be a help to others. With regard to the size of the engine, at present they were not building, for this purpose, cylinders larger than 150 h.p. To get larger powers they had to multiply the number. They would not stop at that size, but it was an indication of what was being done. He quite agreed with Mr. Saxon's view that any progress should be made very carefully. He would be very pleased and gratified if this problem came up again at a later date in the hands of some

(Mr. Chorlton.)

other engineers who would give the results of their thoughts since this Meeting.

In replying to a vote of thanks moved by Mr. Bickerton, the CHAIRMAN (Mr. Adamson) said the Committee of the Club were only too glad to welcome the Institution, as the holding of such meetings was one of the main objects of the Club.

A GRAPHICAL METHOD OF FINDING INERTIA FORCES.

BY WILLIAM J. DUNCAN, B.SC., *Graduate*, OF GLASGOW.

[*Selected for Publication only.*]

Introductory Remarks.—The object of this Paper is to develop a graphical process for the solution of certain problems in the dynamics of machines. The constructions are simple in themselves, but the proofs involve a fairly complete discussion of the motion of a plane lamina. In order to avoid overburdening the Paper with mathematics, a general explanation of the terms used and the constructions employed is first given. This is followed by detailed applications of the method to some practical examples. Finally, in the Appendix (page 233) there are systematic proofs of all the constructions enunciated before.

In the graphical processes which are given below, the determination of the point called the "acceleration centre" is fundamental. This is easy when the "circle of inflexions" has been constructed. Hence the Paper commences with explanations of these terms, followed by constructions for the circle of inflexions. Then come methods of finding the acceleration centre, and finally the line of action and magnitude of the inertia force.

PART I.—DESCRIPTION OF THE CONSTRUCTIONS AND DEFINITIONS OF TERMS.

(1) Consider a rigid body moving in any manner in a plane. At any instant there is a point in the body which is momentarily

at rest relative to the plane of reference.* This point is called the "instantaneous centre." Likewise there is a point, generally distinct from the instantaneous centre, which has zero acceleration at the instant.† This point is termed the "acceleration centre" of the body for the instant considered. All lines drawn in the body are rigidly connected together. Hence they have always the same angular velocities and accelerations at the same moment. Denote this common angular velocity by ω and the angular acceleration by a.

Let P, Fig. 1, be any point of the body and I the instantaneous centre. Then the velocity of P is perpendicular to IP and equal

FIG. 1.

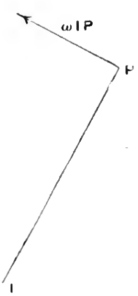


FIG. 2.

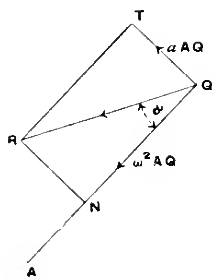
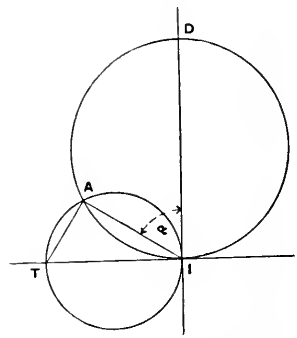


FIG. 3.



to ωIP in magnitude.† In Fig. 2 let A be the acceleration centre and Q any point. Then the acceleration of Q $= \text{AQ}\sqrt{\omega^4+a^2}$ in magnitude and is inclined at α to AQ where $\tan\alpha = \frac{a}{\omega^2}$.†

(2) It is now necessary to define and describe the circle of inflexions, since it is fundamental in the constructions which are given later. It can be shown ‡ that the locus of points in the body, whose respective velocities and accelerations are parallel, is a circle. This curve is known as the circle of inflexions. It is so

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* In practice this would be a plane fixed to the Earth.

† For proof *see* Appendix (page 233).

‡ *See* Appendix, Art. 17 (page 236).

named because any point on it is momentarily at a point of inflexion on its path. The circle of inflexions passes through the instantaneous centre I and the acceleration centre A, Fig. 3. Let D be the point on the circle opposite I. Then $\angle AID = a$,* the angle defined in Art. 1.

Similarly the locus of points, whose respective velocities and accelerations are perpendicular, is a circle which also passes through A and I. The diameter IT of this circle is perpendicular to ID. This may be called the circle of zero tangential acceleration.

FIG. 4.

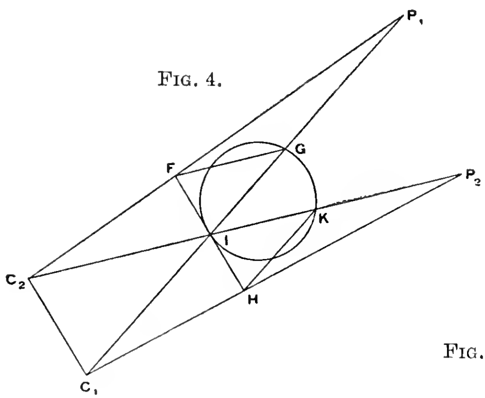


FIG. 5.

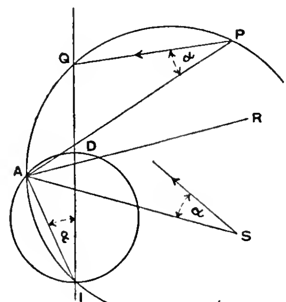
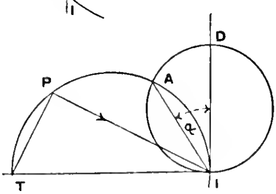


FIG. 6.



(3) As a rule the instantaneous centre I can be easily found, and the methods of doing this are so well known that they need not be described here. On the other hand, the acceleration centre is the very point which it is required to determine. It will be seen that a knowledge of the circle of inflexions goes a long way in fixing its position. Thus a construction for the circle of inflexions is the next requisite. In many cases it is known that a certain point of the body traces a straight line. Such a point always lies upon the circle of inflexions.* Much more frequently, however,

* *See* Appendix, Art. 17 (page 236).

the positions of the centres of curvature of the paths of two points of the body are known, as is evident on considering most of the well-known mechanisms. When this is so, the circle of inflexions may be constructed as follows, Fig. 4.

Let C_1 and C_2 be the centres of curvature of the paths of P_1 and P_2 respectively. Then the instantaneous centre I is the meet of the lines P_1C_1 and P_2C_2. Join P_1C_2 and P_2C_1 and through I draw FH parallel to C_1C_2. From F draw FG parallel to C_2P_2 to meet P_1C_1 in G, and from H draw HK parallel to P_1C_1 to meet P_2C_2 in K. Then G and K are points on the circle of inflexions. Thus the circle of inflexions is determined, since it passes through the three points I, G, and K.

If only one centre of curvature be known, say C_1, then choose for C_2 any convenient point on P_2I or P_2I produced, and carry out the construction for G exactly as before. This arbitrary choice of C_2 does not invalidate the construction for G. But when two centres of curvature are known, it is convenient to take C_2 at the second centre of curvature. In either case the construction is equivalent to making

$$P_1G \, . \, P_1C_1 = P_1I^2.$$

Hence, if desirable, the position of G (or of K) may be calculated arithmetically. This is specially convenient when G would be a remote point on a drawing.

(4) Having given the circle of inflexions, or data from which it can be determined, and the direction of the acceleration of one point, it is required to construct the acceleration centre. Let P, Fig. 5, be the point the direction of whose acceleration is known. Through P draw PQ parallel to this direction to meet the diameter ID or ID produced, of the circle of inflexions in Q. Through P, Q and I describe a circle which cuts the circle of inflexions again at A. Then A is the acceleration centre.

If it should happen that Q coincides with I, the construction apparently fails. In this case, however, P must lie on the circle of zero tangential acceleration (*see* Art. 2). Hence the acceleration centre can be constructed as follows, Fig. 6. Join PI and through

P draw PT perpendicular to PI to meet IT, IT being perpendicular to ID. Construct a circle about T, P, and I and let this cut the circle of inflexions again at A. Then A is the acceleration centre.

In the next place, suppose that the magnitude of the acceleration of the point R (which may or may not coincide with P) is known, Fig. 5. Join AR and measure the length of this line. Then from Art. 1 we have (acceleration of R) = AR$\sqrt{\omega^4+a^2}$ from which $\sqrt{\omega^4+a^2}$ can be determined. Also angle $a = \angle$AID (Art. 2). Hence tan a is known and both ω and a can now be calculated if required.

Since a and $\sqrt{\omega^4+a^2}$ are both known, it follows that the acceleration of any point (say S, Fig. 5) can be found, for the magnitude of the acceleration is AS$\sqrt{\omega^4+a^2}$, and its direction is inclined at a to AS (Art. 1).

To sum up, the accelerations of all points, in magnitude and direction, can be found when the circle of inflexions, the direction of the acceleration of one point, and the magnitude of the acceleration of another point are known.

(5) Before discussing the application of the foregoing constructions to the dynamics of machines, it will be well to state briefly the fundamental theorems on the motion of a rigid body in two dimensions. The instantaneous state of acceleration of a body may be considered as due to the action of a single force which is characterized as follows:—

(i) In magnitude it is equal to the mass of the body multiplied by the acceleration of its centre of mass.*

(ii) Its direction is that of the acceleration of the centre of mass.

(iii) Its line of action is such that the moment of the force about the centre of mass is equal to the moment of inertia of the body about the centre of mass multiplied by the angular acceleration of the body.

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* The force is then measured in absolute units. To reduce to ordinary or gravitational units this must be divided by g.

(6) Let G, Fig. 7, be the centre of mass of the body and A the acceleration centre. The acceleration of G is in magnitude $AG\sqrt{\omega^4 + \alpha^2}$ and is inclined at α to AG (Art. 4). Hence if M be the mass of the body, the magnitude of the inertia force R is given by

$$R = M \times AG\sqrt{\omega^4 + \alpha^2}$$

and R is inclined at α to AG.

Thus it only remains to find the line of action of R.

Fig. 7.

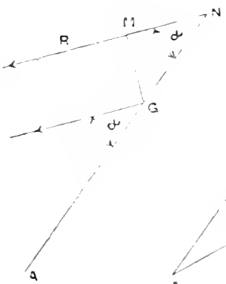


Fig. 8.

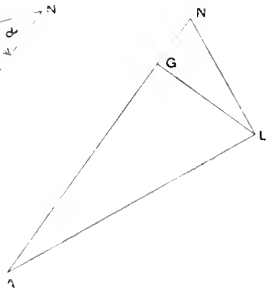
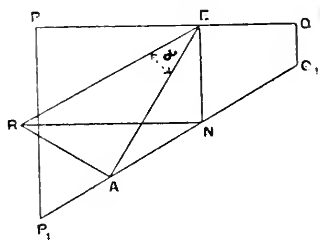


Fig. 9.



It can be shown* that condition (iii) Art. 5 leads to the result that R passes through the point N on AG which is such that

$$XX' = K^2$$

where $$X = AG$$

$$X' = GN$$

and K = radius of gyration of the body about the centre of mass.

It will be observed that N is the "centre of percussion" when A is the "centre of suspension."*

The point N can be constructed geometrically as follows, Fig. 8. At G erect GL perpendicular to AG and equal to K the radius of gyration about G. Join AL and draw LN perpendicular to AL to cut AG produced in N. Then N, so determined, is the point required.

(7) It will now be well to state the outline of the method used in attacking a problem.

* *See* Appendix, Art. 22 (page 239).

First the circle of inflexion is constructed. The methods already given are frequently suitable for this. Some other cases are illustrated among the examples. The acceleration centre is then determined from knowledge of the acceleration of one point. This incidentally determines the angle α, while the value of $\sqrt{\omega^4 + a^2}$ can be found if the magnitude of the acceleration of any point be known. The acceleration of the centre of mass can now be deduced at once. Lastly, from a knowledge of the kinetic constants M and K of the body, the inertia force can be completely determined, as explained in the last article.

(8) Before passing on to the examples, a further useful application of the acceleration centre will be explained. If a straight bar be in a state of acceleration, the effect of the inertia of its parts is the same as if it were under the action of an oblique load which varies in direction and intensity from point to point. The component of this load, perpendicular to the bar, sets up a bending action which may be considerable. For example, in the case of locomotive coupling-rods, the consideration of this bending action has a large share in fixing the design.

Whenever the acceleration centre has been found, the load curve on a uniform straight bar is very easily constructed. Let PQ, Fig. 9, be such a bar, whose mass per unit length is m. The load curve is the straight line P_1Q_1 which passes through A and is inclined at α to PQ. The force scale is $\dfrac{m\,l\,\omega^2}{g}$

where l = linear scale

and ω = angular velocity of the bar.

The actual bending moment, of course, depends on the method of supporting the bar, and can be found in the usual way.

PART II.—EXAMPLES.

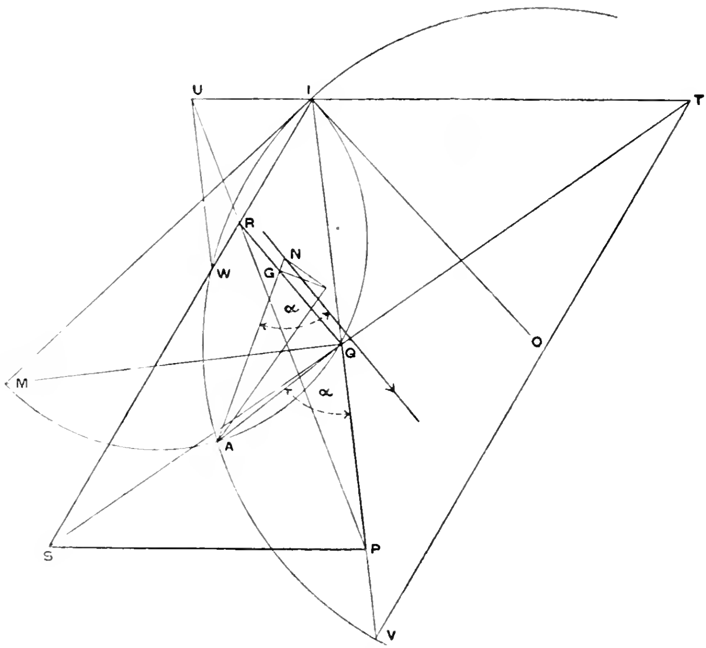
(9) The methods which have been explained will be exemplified by the discussion of the motion of the link RQ of a four-bar mechanism, Fig. 10. The particulars of this linkage are as follows:—

Q 2

$$SR = 1 \cdot 2' \qquad RQ = 0 \cdot 5' \qquad QP = 0 \cdot 65'$$
$$PS = 1 \cdot 0' \qquad \angle RSP = 60^\circ.$$

G, the mass centre of the bar RQ, lies on RQ, and RG $= 0 \cdot 2'$. The mass of RQ = 20 lb. The radius of gyration about G $= 0 \cdot 15'$. QP is supposed to rotate 120 times per minute, so that $\Omega = 4\pi$ radians per second.

FIG. 10.



As a first step towards the solution, the circle of inflexions must be constructed. Now S is the centre of curvature of the path of R, and P that of Q. Hence the construction of Art. 3 may be employed. Thus produce SR, PQ to meet in I, and through I draw UIT parallel to SP. Join PR, SQ, and produce them to cut UIT in U and T respectively. Through T draw TV parallel to RS to cut QP in V, a point on the circle of inflexions. The point W is found by drawing UW parallel to IP. Then the circle of inflexions is constructed about I, V and W. O is its centre.

QP is taken to revolve uniformly; hence Q lies on the circle of zero tangential acceleration, the diameter IM of which is perpendicular to IO. This circle is drawn in. Let it cut the circle of inflexions in A. Then A is the acceleration centre. Join AQ. The acceleration of Q is in the direction QP. Therefore

FIG. 11.

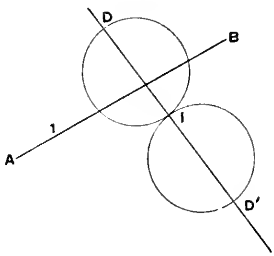


FIG. 12.

B = Centre of Trunnions.
O = Centre of Crank-shaft.
OA = Crank.
BA = Centre line of Cylinder and Piston-Rod.

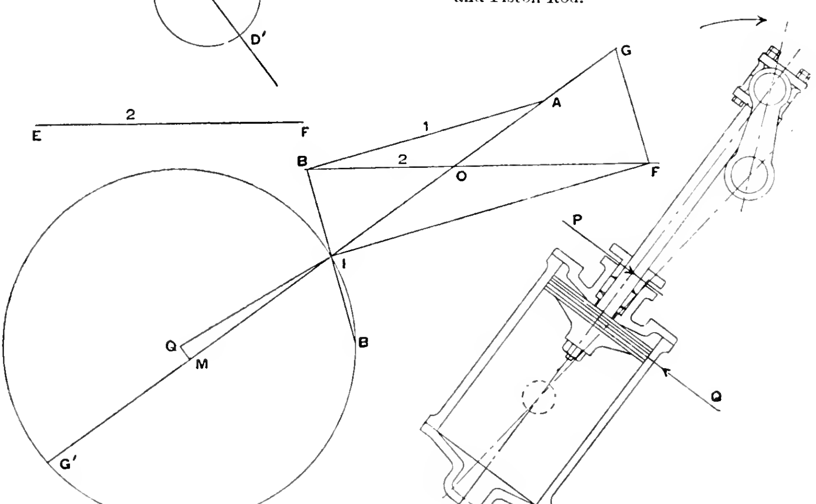


FIG. 13.

$\angle AQP = \alpha$, and so this angle is determined. The magnitude of the acceleration of Q $= \Omega^2$. QP $= 16\pi^2 \times 0{\cdot}65 = 102{\cdot}5$ feet per sec.^{2}. But this $= AQ\sqrt{\omega^4 + \alpha^2}$, and AQ is found to be $0{\cdot}453'$;

$$\therefore \qquad 102{\cdot}5 = \sqrt{\omega^4 + \alpha^2} \,.\, \times 0{\cdot}453\,;$$

$$\therefore \qquad \sqrt{\omega^4 + \alpha^2} = 226{\cdot}0.$$

Thus the accelerations of all points are now completely determinate.

To find N, a point on the line of action of the accelerating force, the construction of Fig. 8 (page 218), is used, taking $GL = 0\cdot 15'$. Through N the line of action of the force is drawn, making an angle a with AN.

It now only remains to find the magnitude R of the accelerating force. From the figure, AG is found to be $= 0\cdot 562'$;

$$\therefore \quad \text{acceleration of G} = 0\cdot 562 \times 226$$
$$= 127 \text{ feet per sec.}^2.$$

The mass of the body is 20 lb.

$$\therefore \qquad R = \frac{127 \times 20}{32} \text{ lb. weight}$$
$$= 79\cdot 3 \text{ lb. weight.}$$

(10) In many cases the solution of problems is greatly simplified by finding the circle of inflexions for the inverted * motion. To explain this, let AB (bar 1) and EF (bar 2), Fig. 11, be two bars of a mechanism so connected that their relative motions are perfectly definite. First consider that bar 2 is fixed; then let I be the instantaneous centre for the relative motion of bars 1 and 2, and let ID be the circle of inflexions for the motion of bar 1 relative to bar 2. Next let bar 1 be fixed, and take the bars in the same relative position as before. Then it can be shown † that the circle of inflexions for the motion of bar 2 relative to bar 1 is ID′, where D′I = ID and D′ is on the opposite side of I to D. Hence, if the circle of inflexions for the inverted motion can be found, it can also be found for the original motion. The usefulness of this result will be illustrated by the next example.

(11) As a case of the use of the principle explained above, consider the oscillating cylinder mechanism, Fig. 12. Let BA be the bar 1 and BO the bar 2. Consider the piston-rod AB to be fixed; then 2 moves as if it were the connecting-rod of an ordinary engine. In this motion B traces a straight line, and therefore lies upon the circle of inflexions. Another point G on the circle of inflexions is

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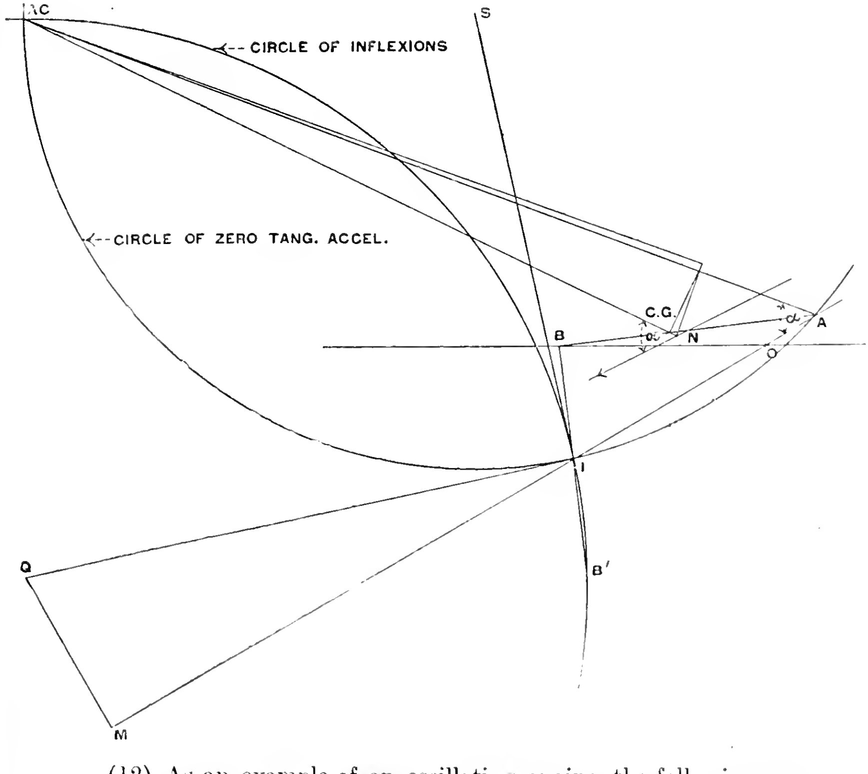
* A motion is said to be inverted when the relative motions remain unaltered, but a different bar is regarded as fixed.

† *See* Appendix, Art. 24 (page 241).

found by using the construction of Fig. 4 (page 215), using B in place of the second centre of curvature C_2. B′ and G′ are taken on BI and GI, which are equal to IB′ and IG′ respectively. Then the circle of inflexions for the motion of the bar 1 relative to the bar 2 passes through the points I, B′, and G′. After this has been found, the dynamical problems can be worked out as before.

FIG. 14.



(12) As an example of an oscillating engine, the following case will be worked out. This is a large engine, shown diagrammatically in Fig. 13, the principal dimensions of which are given below.

Crank radius	=	2 feet 9 inches.
Distance from centre of crank-shaft to centre of trunnions	=	9 ,, 8 ,,

Length of piston-rod from centre of crank-pin to centre of piston	=	9 feet 0 inches.
Approximate mass of cylinder	=	$7\frac{1}{2}$ tons.
Mass of piston and piston-rod	=	2 ,,
Distance of centre of mass of the piston and piston-rod from centre of piston . . .	=	1·97 foot.
Moment of inertia of the piston and piston-rod about centre of mass	=	54,200 lb. feet².
Moment of inertia of cylinder about trunnions .	=	111,000 lb. feet².
Revolutions per minute	=	30.

As the inertia forces are usually large when the crank is near a dead centre, the diagram, Fig. 15 (page 226), has been drawn for the crank at 30° from the out dead-centre. The distance AG, Fig. 12, is here large, and hence it has been found convenient to calculate it in preference to constructing it geometrically as explained in Art. 11.

The diagram, Fig. 14, was drawn before reduction to a scale of 1 inch = 3 feet. Hence, taking lengths as measured on the diagram, the length AG, Fig. 12, must be determined from the relation

$$AO \,.\, OG = OI^2 \text{ (\textit{see} Art. 3)},$$

or

$$0{\cdot}916\ OG = 3{\cdot}5^2$$

$$\therefore \quad OG = 13{\cdot}37 \text{ inches}$$

$$\therefore \quad IG = OG + OI = 13{\cdot}37 + 3{\cdot}5$$

$$= 16{\cdot}87 \text{ inches.}$$

In Figs. 12 and 14 let M be the mid point of the chord IG′ of the circle of inflexions. Then in this case $IM = \frac{1}{2}\,IG = 8{\cdot}43$ inches, and so M is determined. The point Q, which is the centre of the circle of inflexions, lies on a perpendicular to IM through M and also on the line bisecting IB′ at right angles, and hence Q is constructed and the circle of inflexions drawn in.

The point A is moving uniformly in a circle, and hence lies upon the circle of zero tangential acceleration. Also the diameter of this circle which passes through I is perpendicular to IQ. Hence S, the centre of this circle, is the point where a perpendicular to IQ through I cuts the line bisecting IA at right angles. The circle of zero tangential acceleration is thus determined, and the point AC where it cuts the circle of inflexions is the acceleration centre.

The angular velocity of OA in radians per sec. $= 2\pi \times \frac{30}{60} = \pi$

$$\therefore \text{ Acceleration of A} = \pi^2 \times 2\cdot75$$
$$= 27\cdot1 \text{ feet per sec.}^2.$$

Measuring off the diagram, AC to A = $13\cdot4$ inches,

$\therefore$ Scale of acceleration is 1 inch = $2\cdot02$ feet per sec.^{2}.

The distance from the acceleration centre to the centre of mass of the piston and piston-rod = $11\cdot4$ inches,

$$\therefore \quad \text{Acceleration of centre of mass} = 11\cdot4 \times 2\cdot02$$
$$= 23\cdot03 \text{ feet per sec.}^2.$$

$$\therefore \text{ Magnitude of accelerating force in lb. weight} = \frac{23\cdot03 \times 4{,}480}{32}$$
$$= 3{,}200 \text{ lb. weight (roughly).}$$

The angle $\alpha = 50° \ 30'$ from the diagram.

$$\therefore \qquad \tan\alpha = 1\cdot213 = \frac{a}{\omega^2}.$$

ω = angular velocity of piston-rod and also of cylinder

$$= \frac{\text{vel. of A}}{\text{IA (feet)}} = \frac{\pi \times 2\cdot75}{13\cdot23}$$
$$= 0\cdot653 \text{ radians per sec.}$$

$\therefore$ a = angular acceleration of the piston-rod and of the cylinder

$$= 1\cdot213 \times 0\cdot653^2$$
$$= 0\cdot518 \text{ radians per sec.}^2.$$

$\therefore$ Moment of forces acting on cylinder about centre line of trunnions $= \dfrac{0\cdot518 \times 111{,}000}{32}$

$$= 1{,}795 \text{ lb. feet.}$$

Calculation of the Reactions due to Inertia, Fig. 15.—Let R be the accelerating force on the piston and piston-rod. Then R must be the resultant of the various forces acting on the piston and piston-rod. As the effect of *inertia only* is being studied, the steam pressures and weights of the moving parts are left out of account. These produce their own effects on the reactions, which may be calculated separately.

Let F in the diagram be the resultant action of the piston and piston-rod on the cylinder. Then, if friction be neglected, F will be perpendicular to the centre line of the cylinder and its moment about O must be 1,795 lb. feet in order to accelerate the cylinder. Thus, if the distance from B to the line of action of F be l, it follows that $Fl = 1{,}795$. (1)

Let the reaction of the crank-pin on the piston-rod at A be F inclined at θ to the axis of the piston-rod. Then R is the resultant of F_1 and $-$ F. By measurement from the diagram it is found that R cuts the axis at a distance of 6·18 feet from B and is inclined at 18° to the axis.

Components of R perpendicular to the axis = sum of components of F_1 and $-$ F perpendicular to the axis.

$$\therefore \qquad 3{,}200 \times \sin 18^\circ = F_1 \sin \theta - F \qquad (2)$$

FIG. 15.

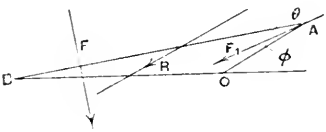


FIG. 17.

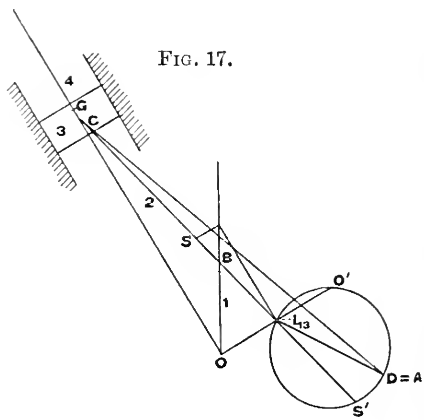
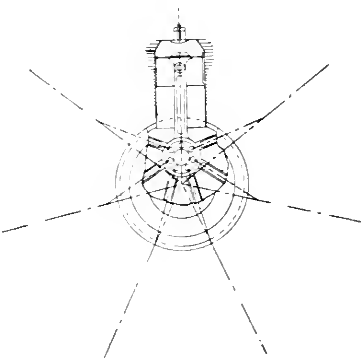


FIG. 16.



Also component of R parallel to the axis = sum of components of F_1 and $-$ F parallel to the axis.

$$\therefore \qquad 3{,}200 \cos 18^\circ = F_1 \cos \theta,$$

$$\text{or } F_1 \cos \theta = 3{,}040 \qquad (3)$$

Finally, the moment of R about B = sum of the moments of F_1 and $-$ F about B.

From equation (1) the moment of $-$ F about B is $-$ 1,795 lb. feet.

$$\therefore\ 3{,}200 \times 6 \cdot 18 \times \sin 18^\circ = F_1 \sin \theta \times 12 \cdot 12 - 1{,}795 \qquad (4)$$

$$\therefore \qquad F_1 \sin \theta = \frac{1{,}795 + 6{,}100}{12 \cdot 12} = 650 \text{ lb. weight,}$$

$\therefore$ Combining with equation (3)

$$F_1 = \sqrt{3{,}040^2 + 650^2} = 3{,}110 \text{ lb. weight,}$$

$$\text{and } \tan\theta = \frac{650}{3{,}040} = 0{\cdot}214,$$

$$\therefore\ \theta = 12^\circ\ 5'$$

Equation (2) now gives F = − 340 lb. weight.

Now F is the resultant of the forces P and Q, Fig. 13 (page 221), whose lines of action are distant 4·8′ and 3·08′ respectively from the centre of the trunnions.

$$\text{Then } Q = P + 340,$$

$$\text{and } P \times 4{\cdot}80 - Q \times 3{\cdot}08 = 1{,}795,$$

$$\therefore\ P\,(4{\cdot}80 - 3{\cdot}08) = 1{,}795 + 340 \times 3{\cdot}08,$$

$$\therefore\ P = 1{,}653 \text{ lb. weight.}$$

$$\text{and } \therefore\ Q = 1{,}993 \text{ lb. weight.}$$

Lastly, the effect of F_1 on the crank effort will be determined:

$$\text{Angle BOA} = 23^\circ\ 30'$$

$$\therefore\ \text{Angle } \phi \text{ (Fig. 15)} = 23^\circ\ 30' - 12^\circ\ 5'$$
$$= 11^\circ\ 25'$$

$$\therefore\ \text{helping moment due to } - F_1,$$
$$= 3{,}110 \times 2{\cdot}75 \times \sin 11^\circ\ 25'$$
$$= 1{,}690 \text{ lb. feet.}$$

Thus the effect of inertia, when the engine is in the position shown, is to increase the crank effort by the amount of 1,690 lb. feet.

(14) Another example of the method of determining inertia forces is afforded by the Gnôme engine. In case the reader is unfamiliar with the construction of this engine, a short description of it may be useful. The engine, Fig. 16, has seven cylinders arranged symmetrically and in one plane on a cylindrical crank-case. The connecting-rod of the cylinder, which is shown vertical, bears on the gudgeon-pin at the top end and on a fixed crank-pin at the lower end. The big end of this master connecting-rod is enlarged so as to take six pins, which pass through bushes on the six remaining connecting-rods. Hence, when the engine is working, the cylinders and crank-case rotate, and the various pistons move

in a perfectly definite manner with regard to each other, since they are all linked up to the master connecting-rod. In the 80-h.p. engine the inlet valve is automatic and situated in the piston-head, while exhaust is overhead and mechanically operated in the usual manner. Further details are of no importance in dealing with the inertia forces due to the motion of the pistons and connecting-rods.

Before working out the forces for a particular engine, it will be well to explain the method of effecting the solution in a general manner. In the first place, consider the motion of the master connecting-rod and its piston, Fig. 17. Here OB is the fixed crank (called member 1), CB (member 2) is the connecting-rod, member 3 is the piston, and 4 is the cylinder and crank-case which revolve about O. The instantaneous centre I_{13} is the meet of CB and a perpendicular to OC through O.

To determine the circle of inflexions for the piston, it is convenient to invert the motion as explained in Art. 10 (page 222). Consider, then, that the member 3 is fixed, and determine the circle of inflexions for bar 1. The point O traces a straight line, and therefore lies upon the circle of inflexions. Again, the centre of curvature of the path of B is at C; hence the point S on the circle of inflexions is determined as in Art. 3 (page 215). The circle of inflexions for the actual motion then passes through O′ and S′

where $$\left.\begin{aligned} OI &= IO' \\ SI &= IS' \end{aligned}\right\}$$
and

Thus the circle of inflexions is found. Next, the angular velocity of the piston is the same as the angular velocity of the cylinder about O, and is taken to be constant. Therefore, the angle α for the motion of the piston is zero (*see* Art. 1). Hence it follows that the acceleration centre A coincides with D, the point on the circle of inflexions which is diametrically opposite I (Art. 2). Then the acceleration of the centroid G of the piston is in the direction GD, and its magnitude is $\Omega^2.GD$ where Ω is the angular velocity of the cylinders, and therefore also of the piston.

The acceleration of the point C of the connecting-rod is in the direction CD. Now B is actually at rest, and therefore is the acceleration centre for the connecting-rod. Therefore α for the

connecting-rod is the angle DCB. The velocity of $C = \Omega . IC$; but it is also equal to $\omega . BC$ where ω is the angular velocity of the connecting-rod.

$$\therefore \qquad \omega = \Omega \frac{IC}{BC}.$$

Then the angular acceleration of the connecting-rod

$$= \omega^2 \tan \alpha$$

$$= \Omega^2 \left(\frac{IC}{BC}\right)^2 \tan DCB.$$

From this the moment of the forces acting on the connecting-rod about B can be determined.

FIG. 18.

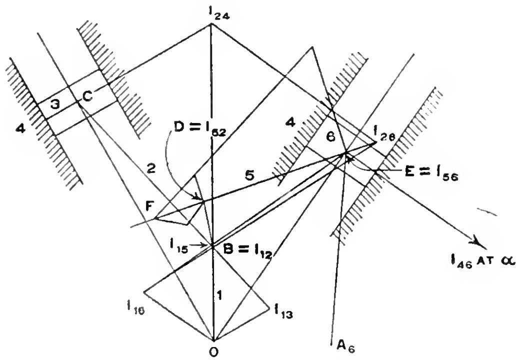
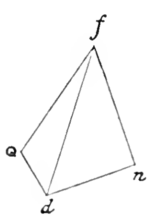


FIG. 19.



The treatment of the other connecting-rods and pistons is not nearly so simple. It is first necessary to determine the instantaneous centres for the piston and connecting-rod. In Fig. 18 the connecting-rod 5 is pinned to the master rod 2 at the point D. The eccentricity of this connexion has been purposely exaggerated in the diagram in order to make it clearer; 6 is the piston which is driven by the rod 5. In order to solve the problem, it is necessary to use a theorem, which is extremely useful in dealing with many mechanisms, namely, that the three instantaneous centres for the relative motions of three bodies are colinear.*

* The reader must consult some book on Kinematics or Mechanism for a proof of this.

As a first step towards fixing I_{16} (that is to say, *the instantaneous centre for the relative motion of the links* 1 *and* 6), it is convenient to determine I_{26}. Now I_{24} can be found at once, while I_{64} is the point at infinity on a line perpendicular to the axis of the piston 6. Therefore, by the above theorem I_{26} must lie on a line through I_{24} and perpendicular to the axis of 6. Also I_{26} must lie upon the line I_{52} I_{56} (that is, the line DE). Hence I_{26} is found as the meet of two different lines. The centre I_{16} must lie on the line I_{26} I_{12}, which is now known. But it must also lie on a perpendicular to OE through O. Therefore I_{16} is determined. It is now easy to find I_{15}. This point lies upon the line I_{16} I_{56}, which is known, and also upon the line BD or I_{12} I_{52}. Hence I_{15} is also determined.

A result of practical utility can be deduced from the diagram, for it will be observed that I_{15} very nearly coincides with B, the point which it would occupy if the second connecting-rod 5 were connected uneccentrically to the master-rod. As this occurs in a diagram where the eccentricity is greater than in the actual engine, it is clear that for practical purposes I_{15} may be taken to lie at B, since this enables one to dispense with the somewhat complicated construction which has just been explained. Further, it may be inferred from this that the accelerations of points on 5 are very nearly the same as if it were pinned to the master rod at B. Hence in practice it would be sufficiently accurate to carry out the construction for the inertia forces on these pistons and connecting-rods, just as in the case of the master connecting-rods.

Nevertheless, it is interesting to show how the problem may be worked out without making this assumption, especially as it serves to exemplify the usefulness of acceleration diagrams in connexion with the methods set forth in this Paper (*see* Appendix, Art. 16, page 233).

The line OE rotates with uniform angular velocity Ω. Therefore component of the acceleration of E perpendicular to OE $= 2\dot{r}\Omega$ where $\dot{r}$ = outward radial velocity of E.*

---

* *See* a text-book on Dynamics.

Now the velocity of $E = \Omega \,.\, I_{16}\, E$ and is perpendicular to $I_{16}\, E$. Hence the radial component of this is readily found, and so the component of the acceleration of E perpendicular to OE can be calculated. Now D is common to the members 2 and 5; so, considering it to belong to bar 2, its acceleration can be determined. Hence also the component of this acceleration perpendicular to OE can be found. At E and D set up lengths along parallel lines proportional to these components of acceleration and join the points so obtained by a straight line which cuts DE in F, suppose. Now the component in a given direction of the accelerations of points on a straight line varies linearly along that straight line.* Hence it follows that the component of the acceleration of F in a direction perpendicular to OE is zero, i.e., the acceleration of F is in the direction OE. (In Fig. 18 the construction for F is merely diagrammatic.)

Take a pole Q, Fig. 19, and draw Qd to represent the known acceleration of D. The radial component of the acceleration of F relative to $D = \omega^2 FD$ where ω is the angular velocity of the connecting-rod 5.

$$\left.\begin{aligned} \text{But the velocity of } E &= \Omega \,.\, I_{16}\, E \\ \text{and also } &= \omega \,.\, I_{15}\, E \end{aligned}\right\}.$$

Hence ω can be calculated.

In the diagram, Fig. 19, set off dn to represent $\omega^2 FD$ to scale and parallel to FD. Then draw a line through n perpendicular to dn. The extremity f of the acceleration vector for F must lie somewhere on this line. But it has been proved that the acceleration of F is in the direction OE (Fig. 18). Hence f is the meet of nf and a parallel to OE through Q. To determine A_5, the acceleration centre for the bar 5, construct on FD a triangle similar to fdQ. A_5 is the vertex of this triangle.† Having determined A_5, the inertia force of 5 may be found as before.

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* Appendix, Art. 24 (page 241). The proof given there only requires slight modification.

† *See* Appendix, Art. 16, page 233.

It is now easy to find A_6, the acceleration centre for the piston 6. First determine the acceleration of E, considered as a point of 5. From E set off a line parallel to this acceleration, and on it take A_6 such that:—

$$\text{acceleration of } E = \Omega^2 \, . \, EA_6 \text{ as a vector.}$$

Then A_6 is the required centre, because the angular velocity of the piston is constant, and so the angle α is zero. The problem may now be completely worked out in the usual manner.

Actual Example.—Through the courtesy of Mr. Mervyn O'Gorman, C.B., *Member*, Superintendent of the Royal Aircraft Factory, the author has been able to take measurements of an 80-h.p. Gnôme engine of the old type (that is to say, having inlet-valves in pistons). The engine is dimensioned in millimetres; but, in order that engineers may form a better idea of the forces involved, British units will be used in the following calculation.

The principal dimensions are approximately as follows:—

Bore	=	0·394 foot.
Crank radius	=	0·246 ,,
Centre of mass of piston, above centre of gudgeon-pin	=	0·079 ,,
Radius of gyration of piston about centre of mass (This figure is not really required in the problem discussed here.)	=	0·089 ,,
Mass of piston with inlet-valve, gudgeon-pin, etc., complete	=	2·75 lb.
Length of master connecting-rod, from centre to centre	=	0·74 foot.
Centre of mass, from centre crank-pin	=	0·115 ,,
Diameter of circle on which lie the centres of pins for six ordinary connecting-rods	=	0·24 ,,
Radius of gyration of master connecting-rod about its centre of mass	=	0·237 ,,
Mass of the master connecting-rod, with six pins in position	=	4·56 lb.
Length of ordinary connecting-rod	=	0·623 foot.
Distance of centre of mass of ordinary connecting-rod from centre of gudgeon-pin	=	0·302 ,,
Radius of gyration about centre of mass	=	0·24 ,,
Mass	=	1·0 lb.

After having explained the method of solution so fully, it will

be quite sufficient to work out the inertia force on the piston attached to the master connecting-rod. The solution may be carried further, employing the figures given above. In making the calculation, it will be assumed that the engine is making 1,200 revolutions per minute.

$\therefore \qquad \Omega = 125 \cdot 8$ radians per second.

The construction has been carried out in Fig. 20 (page 234), where

$$\angle COB = 30^\circ.$$

It is found that $\qquad DG = 1 \cdot 15$ foot.

$\therefore$ Acceleration of $G = 1 \cdot 15 \times \Omega^2 = 18{,}200$ feet per sec.^{2}.

Mass $= 2 \cdot 75$ lb.

$\therefore$ Magnitude of inertia force due to piston

$$= \frac{2 \cdot 75 \times 18{,}200}{32} = 1{,}560 \text{ lb. weight.}$$

The Paper is illustrated by 19 Figs. in the letterpress, and is accompanied by an Appendix illustrated by 6 Figs.

APPENDIX.

PROOFS OF STATEMENTS AND CONSTRUCTIONS.

(15) In this place it is proposed to give systematic proofs of the methods which are merely enunciated in the Paper itself. All the results flow very naturally from the consideration of the motion of a plane lamina in its plane. Hence a concise account of this is first given, most of the propositions being deduced from first principles.

(16) Let P and Q, Fig. 21, be two points of such a lamina; it is required to find the acceleration of Q relative to P. The component of the acceleration in the direction QP is $= \omega^2 . QP$,* and the component in the direction at right angles to QP $= a . PQ$, where ω = angular velocity of body and a = angular acceleration

* *See* any text-book on Elementary Dynamics.

of body (*see* Art. 1). The latter component is represented by QT in the figure, and will be in the direction shown when a is positive, if counter-clockwise rotation be taken as positive. Let QN represent the radial component of acceleration, and complete the parallelogram of accelerations QTRN. As in Art. 1, denote the angle RQN by α. Then the resultant acceleration is represented by QR and its magnitude $= \sqrt{\omega^4 . PQ^2 + a^2 . PQ^2} = PQ\sqrt{\omega^4 + a^2}$

and $$\tan \alpha = \frac{a}{\omega^2}.$$

FIG. 20.

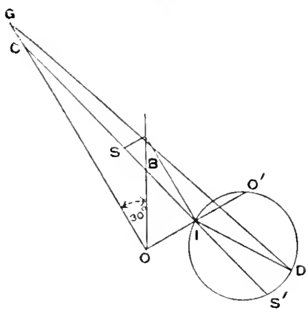


FIG. 21.

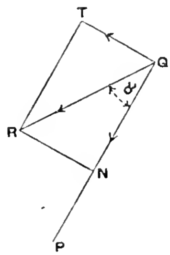
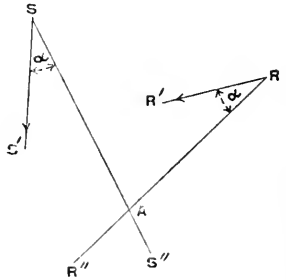


FIG. 22.



Thus the acceleration of Q relative to P is a constant* times PQ in magnitude, and is inclined at a constant angle to QP. It should be observed that when α is positive the angle NQR is described in the negative direction of rotation.

Now let R and S, Fig. 22, be two points whose actual accelerations are in the directions RR′ and SS′ respectively.† Draw RR″ and SS″ at α in the positive direction to RR′ and SS′ respectively. Consider the acceleration of any point on RR″. This acceleration = vector sum of acceleration of R and the acceleration of the point relative to R. But, by the result stated above, the acceleration of the point relative to R is inclined at α

* That is to say, constant for all pairs of points P, Q at a given instant.

† When "actual" acceleration is mentioned, acceleration relative to a certain plane of reference, which is regarded as fixed, is really meant.

in the negative direction to RR″—that is, the acceleration of the point relative to R is in the direction RR′. Therefore, the resultant or actual acceleration of the point is in the direction RR′, or the acceleration may happen to be zero.

In exactly the same way the acceleration of any point in SS″ is in the direction SS″ or is zero. Let RR″ and SS″ meet in A.* Then A is common to the lines, and as its actual acceleration cannot be wholly in two different directions at once, it follows that the acceleration of A is zero. Hence A is the acceleration centre as defined in Art. 1. The actual acceleration of any point X = its acceleration relative to A, and is therefore $= XA\sqrt{\omega^4 + a^2}$ in magnitude, and is inclined at α to XA.

The discussion of the velocities of the several points of the lamina is very similar to the above but even simpler, for the velocity of a point Q relative to another point P is ω . PQ in magnitude, and is perpendicular to PQ. Thus by a proof substantially identical with that already given, the existence of a point whose velocity is zero at the instant may be established. This point is called the instantaneous centre, and will always be symbolized by the letter I. These results have an application to the properties of the velocity and acceleration diagrams. A consideration of the acceleration diagram will be sufficient, as the modifications in the statements which are necessary to suit the case of velocity are obvious.

The acceleration diagram is constructed as follows. A pole O is chosen, and from it a line OX″ is drawn to represent in magnitude and direction the acceleration of the corresponding point X in the body. This is done for any number of points. Now the acceleration of $X = AX\sqrt{\omega^4 + a^2}$ and is inclined at a constant angle α to XA. $\therefore$ OX″ is inclined at α to XA and is proportional to it in length. Hence the polygon or curve formed by a number of points in the body is similar to the polygon or curve formed of their corresponding points in the acceleration diagram. The pole O corresponds to the acceleration centre A. Hence, if by any means the acceleration

* The cases where RR″ and SS″ are parallel or coincident are not of sufficient importance to warrant discussion here.

diagram has been drawn, A can be found by making use of the principle of the similarity of the diagrams, enunciated above. This method of finding A is often useful, and a combination of it with the one more particularly expounded in the Paper has been exemplified in Art. 14.

(17) It is required to find the locus of points whose accelerations are entirely tangential—that is, whose respective velocities and accelerations are parallel (*see* Art. 2). In Fig. 23 let P be a point which satisfies the condition. Let the velocity of P be in the direction PD, which is, of course, perpendicular to IP. If A be the acceleration centre, then the angle DPA must equal a.

$$\therefore \qquad \angle API = \frac{\pi}{2} - a = \text{constant.}$$

Hence it follows at once that the locus of P is a circle passing through A and I. Let D be diametrically opposite I. Then from a property of the circle

$$\angle AID = \angle APD = a.$$

$\therefore$ the acceleration of I is in the direction ID.

Now the motion of the body may be supposed to be due to the rolling of the centrodes which touch at I.

It is easy to see that the acceleration of I must be normal to the centrodes (*see* Art. 24). Hence ID is normal to the centrodes, an interesting result, though not essential to the present argument.

The normal acceleration of a point moving in a curve whose radius of curvature is ρ is equal to $\frac{v^2}{\rho}$ where v is the velocity of the point. Hence, if this normal acceleration be zero, it follows that ρ must be infinite (provided v is not zero, which only occurs at I), i.e., the tracing point must be at a point of inflexion on its path It is from this property that the locus of zero normal acceleration receives the name "circle of inflexions."

In a similar manner it can be proved that the locus of points whose accelerations are entirely normal is a circle (AIE in Fig. 23). Thus let Q be a point whose acceleration is entirely normal so that it is in the direction QI. Since the direction of the acceleration is inclined at a to QA, it follows that $\angle AQI = a$.

$\therefore$ the locus of Q is a circle passing through A and I.

Let E be the point where a perpendicular to DI through I cuts this circle. Then $\angle AEI = \alpha$.

$$\text{But } \angle AIE = \frac{\pi}{2} - \alpha.$$

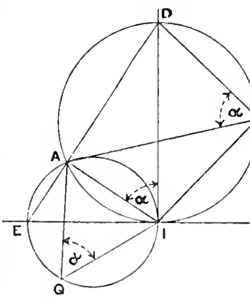
$$\therefore \qquad \angle EAI = \frac{\pi}{2} = \text{one right angle.}$$

Hence it follows that IE is a diameter of the circle of zero tangential acceleration.

Since the angles DAI and EAI are both right angles, the points E, A, and D lie in one straight line. Therefore the point E is

FIG. 24.

FIG. 23.



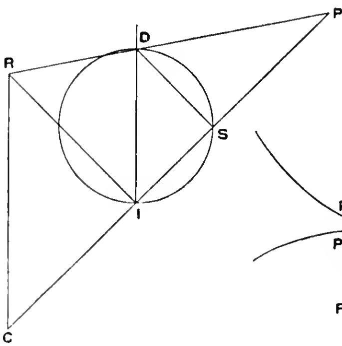
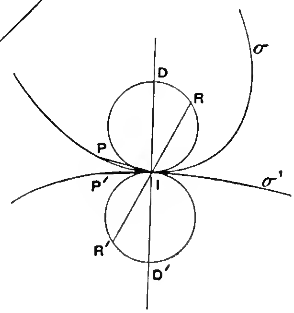


FIG. 25.



constructed by producing AD to cut a perpendicular to ID through I.

(18) The case where the angular velocity ω is constant is important. Here $a = o$, whence also $\alpha = o$.

$\therefore$ D is the acceleration centre, because $\angle AID = \alpha = o$ (Art. 17).

Consider the acceleration of any point P, Fig. 24. As a vector it is equal to $\omega^2 \,.\, PD$. Join PI and let it cut the circle of inflexions in S. Since $\angle DSI$ is a right angle, it follows that the normal and tangential components of the acceleration of P are $\omega^2 \,.\, PS$ and $\omega^2 \,.\, SD$ respectively. This result has a very important application, as will be shown immediately.

(19) Let C, Fig. 24, be the centre of curvature of the path of P. Then, as already remarked, normal acceleration of P $= \frac{v^2}{\rho}$ (*see* Art 17). But $v = \omega \cdot \mathrm{IP}$, $\rho = \mathrm{PC}$, and normal acceleration of P $= \omega^2 \cdot \mathrm{PS}$. Substitute these values in the equation. The result is

$$\omega^2 \cdot \mathrm{PS} = \frac{\omega^2 \cdot \mathrm{IP}^2}{\mathrm{PC}}$$

or $$\mathrm{PS} \cdot \mathrm{PC} = \mathrm{PI}^2.$$

This is a most important result, as it shows that if P, I, and either of the points S and C be known, the remaining one may be found by a simple geometrical construction.

Thus, if the circle of inflexions be known, the point C can be constructed as follows:—Draw IR perpendicular to PI and produce PD to meet it in R. Draw RC parallel to DI to meet PI produced in C. To prove this observe that triangles PSD, PRI are similar,

$$\therefore \quad \mathrm{PS} : \mathrm{PI} = \mathrm{PD} : \mathrm{PR}$$

Also from the similar triangles PDI and PRC it follows that

$$\mathrm{PD} : \mathrm{PR} = \mathrm{PI} : \mathrm{PC}$$

$$\therefore \quad \mathrm{PS} : \mathrm{PI} = \mathrm{PI} : \mathrm{PC}$$

or $$\mathrm{PS} \cdot \mathrm{PC} = \mathrm{PI}^2.$$

The next article deals with the converse problem, namely, that of constructing the circle of inflexions when the centres of curvature of the paths of points are known.

(20) In Fig. 4 (page 215), let C_1 be the centre of curvature of the path of P_1, and C_2 the centre of curvature of the path of P_2. Then P_1C_1 and P_2C_2 are the normals to the paths of P_1 and P_2 respectively. Hence I, the point where they meet, must be the instantaneous centre, and consequently a point on the circle of inflexions. Two other points may be constructed, as explained in Art. 3, but the enunciation is repeated here for the sake of continuity.

Join P_1C_2, P_2C_1 and C_1C_2. Through I draw HF parallel to C_1C_2 and through FH draw FG, HK, parallel to P_2C_2, P_1C_1 respectively. Then the points G and K lie upon the circle of inflexions. To prove this, consider the point G. By similar triangles

$$P_1G : P_1I = P_1F : P_1C_2$$

and $$P_1F : P_1C_2 = P_1I : P_1C_1$$

$\therefore$ $$P_1G \cdot P_1C_1 = P_1I^2$$

$\therefore$ by Art. 19 G is a point on the circle of inflexions.

Similarly K is a point on the circle of inflexions. Since three points on the curve are now known, it is uniquely determined and may be constructed in the usual manner.

(21) Having given the circle of inflexions, or data from which it can be determined, and the direction of the acceleration of one point, it is required to construct the acceleration centre (*see* Art. 4). Let the acceleration of the point P, Fig. 5 (page 215), be in the direction PQ, Q being a point on ID. Suppose that A is the acceleration centre. Then $\angle APQ = a$. But $\angle AIQ = a$ also. Therefore the four points A, I, P and Q are concyclic. Hence to find A it is only necessary to construct the circle about I, P and Q. The second point of intersection of this circle with the circle of inflexions is the acceleration centre. Some particular cases are discussed in Art. 4 (*q.v.*)

(22) A proof of the method of Art. 6 will now be given. The acceleration of G, Fig. 7 (page 218), $= AG\sqrt{\omega^4+a^2}$, and is inclined at a to AG. Hence R, the accelerating force, is inclined at a to AG, and its magnitude is given by

$$R = Mx\sqrt{\omega^4+a^2}$$

where $AG = x$ and M is the mass of the body. Let the line of action of R cut AG in N, where $GN = x'$. If MG be the perpendicular from G on R, then $MG = x' \sin a$.

$\therefore$ the moment of R about $G = \mu$ (say)

$$= Mxx' \sin a\sqrt{\omega^4+a^2}.$$

But $\tan a = \dfrac{a}{\omega^2}$ $\qquad\therefore\quad \sin a = \dfrac{a}{\sqrt{\omega^4+a^2}}$

$$\therefore\quad \mu = Maxx'.$$

By the third principle of dynamics enunciated in Art. 5, $\mu = Ma\,K^2$ where K is the radius of gyration of the body about G.

Equating values of μ:—

$$Maxx' = Ma\,K^2$$

or

$$xx' = K^2.$$

That N is the centre of percussion when A is the centre of suspension may be proved as follows: Let A be actually fixed; then, as the acceleration of A is zero, it must be the acceleration centre. Hence the resultant of the applied force (or impulse) and the reaction at A must pass through N. Therefore, if the reaction at A is to vanish, it is necessary that the line of action of the applied force should pass through N. This is precisely the property of the centre of percussion.

It is required to prove the geometrical construction for N, enunciated in Art. 6. In Fig. 8 (page 218) observe that the triangles AGL and LGN are similar;

$$\therefore \qquad AG : GL = GL : GN,$$

$$\text{or} \qquad AG\,.\,GN = GL^2,$$

$$\text{i.e.} \qquad xx' = K^2,$$

which proves the construction.

(23) In Art. 8 is given a construction for finding the bending load on a straight bar due to its inertia. This construction will now be proved.

Refer to Fig. 9 (page 218). Consider a small element of the bar of length ds at E. The acceleration of E is in the direction ER inclined at α to EA. The magnitude of the acceleration

$$= AE\sqrt{\omega^4 + a^2}$$

$$= \omega^2.AE \sec\alpha, \text{ since } \sec\alpha = \frac{\sqrt{\omega^4 + a^2}}{\omega^2}$$

$$= \omega^2.RE$$

where RA is perpendicular to AE. Therefore, the accelerating force on the element $= m\omega^2.RE.ds$

where $\qquad m =$ mass of unit length of bar.

Resolve ER into EN $\perp r$ to PQ and NR parallel to PQ. Then the component of the accelerating force perpendicular to PQ $= m\omega^2.EN.ds.$

The angles RAE and RNE are right.

$\therefore$ the points R, A, N and E are concyclic.

$\therefore$ $\angle RNA = \angle REA = \alpha$.

$\therefore$ the locus of N is a straight line through A and inclined at α to PQ. Hence, to a suitable scale, the load area on PQ is the trapezium PQQ_1P_1.

Besides the lateral load there is a variable thrust in PQ due to the inertia, and if PQ bend at all, this will give rise to an extra bending moment. The calculation of this would be complicated, and it would probably be so small as to be negligible.

The bending moment due to an independent thrust in PQ may be commensurate with that due to the lateral inertia load. (A case of this kind which has been worked out is that of a coupling-rod of a locomotive.*)

(24) It now remains to prove the statement of Art. 10. This may be done as follows:—

The acceleration of I is in magnitude $= AI\sqrt{\omega^4 + a^2}$ (Fig. 23).

But $AI = DI \cos \alpha = \dfrac{DI \times \omega^2}{\sqrt{\omega^4 + a^2}}$.

$\therefore$ Acceleration of $I = \omega^2 . DI$ and is in the direction ID.

Suppose that the relative motion of two bars of a mechanism can be produced by the rolling of the centrode curves σ and σ^1 (*see* Fig. 25). At a certain instant let P and P′ coincide at the instantaneous centre, and, after an interval τ, let them occupy the positions shown. At the commencement of this interval the points were relatively at rest. At the end of the interval, however, P has a velocity relative to the second bar of magnitude $\omega . IP$ and in a direction ultimately parallel to ID, the normal to the centrodes.

Similarly, the velocity of P′ relative to the first bar is of magnitude $\omega . IP'$ and in a direction opposite to that of P. But $IP = IP'$ in the limit, since there is no slipping at the point of contact of the centrodes. Therefore, these two velocities are equal in magnitude but opposite in direction.

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* Perry, *Phil. Mag.*, March 1892.

Now, acceleration = limiting value of $\left(\frac{\text{change in velocity}}{\text{time of change}}\right)$; therefore the accelerations of P and P′, relative to the second and first bars respectively, are equal in magnitude but opposite in direction.

Let D be the end of the diameter of the circle of inflexions for the motion of the first bar relative to the second, and, similarly, D′ for the motion of the second relative to the first. Then the accelerations of P and P′ are given as vectors by $\omega^2 . \mathrm{ID}$ and $\omega^2 . \mathrm{ID}'$ respectively, as was shown above.

Therefore, as vectors $\mathrm{ID}' = -\mathrm{ID}$, i.e., the length $\mathrm{D'I}$ = length ID, while D and D′ lie on opposite sides of I.

Suppose then that R′ is known to lie upon the lower circle of inflexions. Produce R′I to R, making $\mathrm{R'I} = \mathrm{IR}$. Then R will lie on the upper circle of inflexions.

The Institution of Mechanical Engineers.

PROCEEDINGS.

MARCH 1915.

AN ORDINARY GENERAL MEETING was held at the Institution on Friday, 19th March 1915, at Eight o'clock p.m.; Dr. W. CAWTHORNE UNWIN, F.R.S., President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that, to fill the vacancy among the Members of Council caused by the election of Mr. J. Rossiter Hoyle as a Vice-President, the Council had appointed Mr. Vincent L. Raven a Member of Council. He would retire at the next Annual General Meeting, in accordance with Article 25.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and the following forty-seven condidates were found to be duly elected:—

MEMBERS.

ANFILOGOFF, NICHOLAS ALEXANDER, . . .	Thames Haven.
BENTHAM, CECIL, ...	Manchester.
HUBERT, Professor HERMAN VICTOR, . .	Liége.
REYNOLDS, WILLIAM HENRY, R.D., R.N.R., .	Cardiff.
SAMUELSON, FREDERICK, ...	Rugby.
WATSON, EDWARD AUGUSTUS, ...	Dublin.

WHATNALL, JAMES ALFRED, . . .	London.
WIGHTMAN, JULIAN, ...	Alfreton.
WOOD, MAURICE ARTHUR, . . .	London.

ASSOCIATE MEMBERS.

ALLIBON, SAMUEL, ...	Romford.
ARMFIELD, JOSEPH HAROLD, . . .	Ringwood, Hants.
ARTHUR, HENRY HERBERT, . . .	Carmarthen.
BROWN, JAMES ELLES, ...	London.
EARP, ARTHUR CLIFFORD, ...	Shillong, Assam.
EDMONDS, HENRY THOMAS GEORGE, . .	Chester.
FLETCHER, WILLIAM MARSDEN, . . .	Liverpool.
GILLESPY, GEORGE THOMAS, . . .	London.
GLADWYN, ALLEN EDWARD, . . .	London.
HALE, HAROLD GODFREY, ...	London.
HINES, JOHN SYDNEY, ...	Manchester.
HIRST, WILLIAM DOUGLAS, . . .	Jubbulpore.
HOWELL, WILLIAM SIDNEY, . . .	London.
JOHNSON, ROBERT CHARLES, . . .	Bardon Hill.
JOHNSTON, JOHN ALBERT, ...	Wednesbury.
MACDONALD, WILLIAM ROBERTSON, . .	Dundee.
MCFADYEN, ALEXANDER, ...	Dunedin, N.Z.
PAVITT, EDWIN GEORGE, ...	London.
PERKINS, CHARLES BROADBENT, . . .	Sheffield.
RICHARDS, CLIFFORD CHARLES, . . .	Stockport.
SANDERS, HAROLD WILLIAM, . . .	Manchester.
SCOBLE, WALTER ALFRED, . . .	London.
SHEPHARD, HARRY, ...	Coventry.
SMITH, HORACE REGINALD, . . .	Smethwick.
SPINK, REGINALD JOHN, ...	Vancouver.
TAYLOR, ARTHUR, ...	Bloemfontein.
THOMS, ALEXANDER KEAY, . . .	Shamnagar, Bengal.
TOPHAM, EDWIN FREDERICK BENT, . .	Cerro Azul, Peru.
WARD, EDGAR PAUL, ...	Leeds.
WILSON, WILLIAM BROWN, . . .	London.
WOODS, ERNEST EDWIN, ...	Bombay.
WRIGHT, Professor HARRY THOMAS, . .	T'angshan, N. China.

GRADUATES.

BATER, KENNETH COURTENAY, . . .	Derby.
GLINN, ROY JAMES, ...	London.
PARKER, LAWRENCE GEORGE, . . .	London.
PILE, WILLIAM DEVEREUX, . . .	London.
RICHARDSON, OSWALD EDWARD, . . .	London.
WILLIAMS, NORMAN HOOPER, . . .	London.

The President announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

Bullock, Richard Cecil, . . .	Bath.
Burt, Leslie Newman, . . .	London.
Marshall, William Henry Upton, .	Weymouth.
Paris, Patrick Alfred, . . .	Kuala Lumpur, F.M.S.

The following Paper was read and discussed:—

"The Chemical and Mechanical Relations of Iron, Cobalt, and Carbon"; by Professor J. O. Arnold, D.Met., F.R.S., of the University of Sheffield, and Professor A. A. Read, D.Met., F.I.C., of the University of Wales, Cardiff.

The Meeting terminated at Half-past Nine o'clock. The attendance was 62 Members and 21 Visitors.

THE CHEMICAL AND MECHANICAL RELATIONS OF IRON, COBALT, AND CARBON.

By J. O. ARNOLD, D.Met., F.R.S.,
Professor of Metallurgy in the University of Sheffield,

and

A. A. READ, D.Met., F.I.C., of Cardiff,
Professor of Metallurgy in the University of Wales.

Summary of the Work of Previous Investigators.—Sir Robert Hadfield, at the Engineering Congress of the Institution of Civil Engineers held in 1897, described some experiments made by him (in 1891) on the influence of Cobalt on Steel. His general conclusion was that its action resembled that of nickel in raising the elastic limit and maximum stress of the material. The cost of the cobalt used was about 29*s.* per lb. In 1904, in the first number of *The Iron and Steel Metallurgist* (pages 10–12), he published his results in greater detail. They are embodied in Table 1 (page 248).

Guillet * states that steels ranging up to 40 per cent. of cobalt are all pearlitic, even when they contain 0·8 per cent. of carbon. The presence of cobalt slowly raises the tensile strength and the elastic limit, while the elongation and reduction of area are diminished. There is no sudden alteration in the mechanical properties, which are only gradually changed.

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* Journal, Iron and Steel Institute, 1906, No. 2, page 18.

TABLE 1.

Showing Results of Hadfield's Pioneer Experiments on Cobalt Steel.

The ingots were forged down to bars $1\frac{1}{4}$ inch in diameter. The size of the test-pieces was 2 inches parallel by 0·798 inch diameter.

Mark.	C.	Si.	S.	P.	Mn.	Co.	Mechanical Tests on Unannealed Bars.				Mechanical Tests on Annealed Bars.			
							Elastic Limit.	Maximum Stress.	Elongation.	Reduction of Area.	Elastic Limit.	Maximum Stress.	Elongation.	Reduction of Area.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.	Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
A	0·20	0·64	0·10	0·06	0·80	absent	27	37	24	28	20	31	35	46
B	0·16	0·61	0·10	0·07	1·04	0·53	27	38	29	43	22	31	34	47
C	0·25	0·64	0·11	0·07	1·04	1·80	25	41	19	24	23	35	29	39
D	0·38	1·21	0·14	0·07	0·65	2·50	38	52	15	15	27	43	14	24
E	0·55	0·69	0·11	0·06	0·79	4·46	37	57	15	17	25	46	19	22
F	0·52	0·75	0·14	0·06	0·79	6·91	not taken	55	14	13	30	44	22	25

G. Boecker * found that pure cobalt at about 1,700° C. (3,092° F.) is capable of dissolving 3·9 per cent. of carbon, which separates almost entirely as graphite on cooling. The eutectic point is at 1,300° C. (2,372° F.) and 2·8 per cent. of carbon, and at this temperature cobalt retains 0·82 per cent. of carbon in solid solution. As the temperature falls, the solubility of carbon in solid cobalt diminishes, reaching about 0·3 per cent. at 1,000° C. The general form of the curve resembles closely that of the iron-carbon system. A cobalt carbide has not been detected. The microsections show a well-developed eutectic structure, having as components graphite and the solid solution.

Method of Manufacture of the Cobalt Steels used for this Research.

Five ingots were melted by coke in white crucibles from pure "Thermit" cobalt, Swedish bar iron, and Swedish white iron, all charged together, and small quantities of pure metallic manganese and aluminium were added ten minutes before teeming. The steels were cast into moulds of about 2 inches square, each ingot weighing about 36 lb. The ingots were re-heated and hammered down into bars 1 inch round.

Chemical Analyses of Turnings taken from the Hammered Bars.—The specimen turnings registered per cent. on analysis the figures recorded in Table 2 (page 250).

Turning Characteristics of the Five Steels.—In the lathe, little or no difference could be detected whilst the bars were being turned. All were reported as "tough," which word has reference to the capabilities of the steels to curl off the turning tool in spirals.

Static Mechanical Tests.—The static (tensile) tests were made on test pieces turned down to 2 inches parallel with a diameter of 0·564, equivalent to $\frac{1}{4}$ of a square inch in area. The results are embodied in Table 3 (page 251).

* *Metallurgie*, vol. ix, page 296.

It is a little difficult exactly to summarize the results in Table 3 owing to some irregularities in the carbon contents of the steels. But it may reasonably be deduced that, with equal carbons, the tenacity of the steels, as measured by the yield-points and maximum stresses, increases with the cobalt, whilst the ductility, as measured by the elongation per cent., correspondingly falls. Steel No. 1492 is abnormal, the reduction of area being low, a fact the authors cannot explain except by an assumption that it was finished under the hammer at a lower temperature than the other steels.

TABLE 2.

Analyses of Specimens of Steel.

(Hammered Bars.)

Fig. Plate 1.	Steel No.	Combined Carbon.	Graphite.	Cobalt.	Silicon.	Manganese.	Phosphorus.	Sulphur.	Aluminium.
2	1492	0·64	0·00	2·68	0·05	0·16	0·02 or under	0·04 or under	0·02 or under
3	1493	0·62	0·00	5·50	0·07	0·18			
4	1500	0·84	0·00	11·18	0·09	0·23			
5	1495	0·93	0·00	16·97	0·10	0·23			
7	1496	0·72	0·07	20·85	0·11	0·25			

The authors refrained from normalizing the steels for fear of precipitating graphite. The mechanical influence of the precipitation of the total carbon (0·93 per cent.) present in steel No. 1495, Fig. 6, as graphite by the annealing operation is very remarkable.

Dynamic Mechanical Tests.—These were made on the Arnold alternating stress-strain machine under standard conditions, namely, total length of test-piece, 6 inches; length under test from zero of stress to plane of maximum stress, 3 inches; diameter of test-piece, $\frac{3}{8}$ inch; deflection on each side at zero of stress, $\frac{3}{8}$ inch; rate of alternation, 650 per minute. The results are set forth in Table 4 (page 252).

TABLE 3.

Plate 1. Fig.	Steel No.	Dominating Chemical Composition per cent.			Static (tensile) Tests on Bars as received from Forge.				Fractures.
		Combined Carbon.	Graphite.	Cobalt.	Yield-Point.	Maximum Stress.	Elongation on 2 inches.	Reduction of Area.	
					Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.	
2	1492	0·64	0·00	2·68	29·2	48·4	17·5	26·7	Crystalline.
3	1493	0·62	0·00	5·50	33·0	48·8	22·5	42·7	Coarsely Granular.
4	1500	0·84	0·00	11·18	32·6	65·0	11·5	21·5	Crystalline.
5	1495	0·93	0·00	16·97	38·0	75·3	9·5	12·7	Crystalline.
6	1495 Annealed	0·00	0·93	16·97	18·9	29 2	23·0	41·9	Black Graphitic.
7	1496	0·72	0·07	20·85	40·0	71·3	11·0	18·9	Finely Crystalline.

Determination of the Carbides.—The method and treatment used for separating the carbides was the same as described in the authors' last Paper:* dilute hydrochloric acid, specific gravity 1·02, being used with a low current density of 0·18 ampere per square inch. The time allowed for electrolysis was from five to six hours. The residues thus obtained were all dark grey in colour. The analyses of the carbides were carried out as follows:—

The carbon was estimated by direct combustion, the carbides burning quite readily. The oxides of iron and cobalt remaining in the boat after combustion were dissolved in hydrochloric acid

TABLE 4.

Plate 1. Fig.	Steel No.	Alternations Endured.			Cobalt.	Carbon.
		1st Test.	2nd Test.	Mean.		
					Per cent.	Per cent.
2	1492	272	212	242	2·68	0·64
3	1493	246	220	233	5·50	0·62
4	1500	140	176	158	11·18	0·84
5	1495	164	184	174	16·97	0·93
7	1496	108	138	123	20·85	0·72

and made up to a known volume. The iron and cobalt were then estimated in separate portions. The results are given in Table 5 (pages 254–5).

A consideration of these results shows that practically the total amount of carbon in each steel was accounted for, the very small loss being to a considerable extent due to the difficulty of getting the bars absolutely clean, and thus obtaining the last traces of carbide.

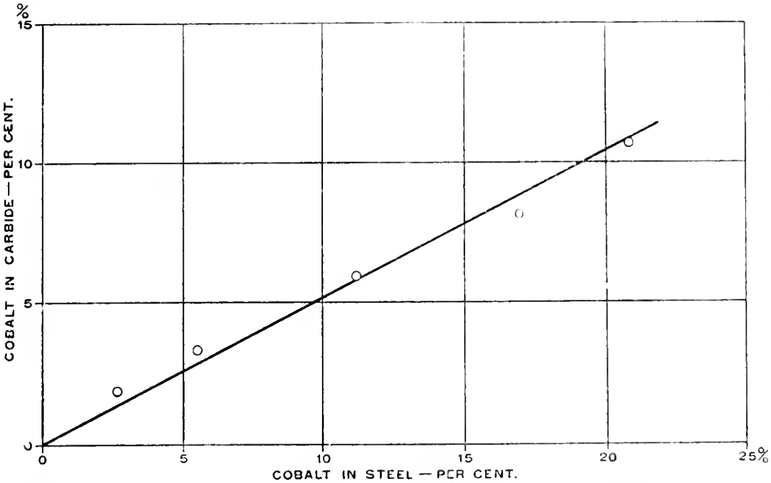
An inspection of the figures set forth in Table 5 also shows that with steels high in carbon and containing up to 20·85 per cent. of cobalt, the carbide Co_3C exists in very small proportions,

* Proceedings, I.Mech.E., 1914, page 223 *et seq.*

only about 5 to 6 per cent. of the total cobalt present in the steel being found in combination with the carbon as carbide, the remaining 94 to 95 per cent. being alloyed with the iron and manganese, Fig. 1.

The Effect of Annealing Cobalt Steels.—The bars were annealed by heating in a gas-fired furnace for a period of about eight hours until an even temperature of about 780° C. (1,436° F.) was obtained,

FIG. 1.—*Hammered Bars.*
Proportion of Cobalt in the Carbide and the Steel.
(See Table 5, pages 254–5.)



soaked at this heat for one hour, the furnace dampered down and the steel allowed to cool down over a period of about 24 hours. The influence of the annealing is shown in Table 6 (page 256).

These figures show that, on well annealing a cobalt steel with 0·64 per cent. of carbon and 2·68 per cent. of cobalt, only a trace of graphite is found. As the percentage of cobalt increases in the next member of the series, a large amount of graphite is precipitated, while in the three remaining steels, with still higher percentages of cobalt, the whole of the carbon is precipitated in the graphitic condition.

TABLE 5 (*continued on opposite page*).

Hammered Bars.

Plate 1. Fig.	Ingot No.	Combined Carbon.	Graphite.	Cobalt.	Grammes dissolved.	Weight of Dry Residue.	Percentage of Total Cobalt obtained with Dry Residue.*	Percentage of Total Combined Carbon obtained with Dry Residue.
		Per cent.	Per cent.	Per cent.				
2	1492	0·64	0·00	2·68	5·0435	0·4215	5·90	91·45
					5·4450	0·4486	5·39	91·13
3	1493	0·62	0·00	5·50	5·2950	0·4148	4·75	92·19
					5·3180	0·4359	4·79	94·98
4	1500	0·84	0·00	11·18	5·3985	0·5577	5·35	90·16
					5·2170	0·5644	5·67	94·07
5	1495	0·93	0·00	16·97	5·3625	0·6691	6·07	96·10
					4·3480	0·5609	5·98	99·93
7	1496	0·72	0·07	20·85	5·4525	0·5706	5·28	99·06
					5·4190	0·5490	5·01	95·42

* *See* Appendix (page 259).

TABLE 5 (*concluded from opposite page*).

Hammered Bars.

Plate 1. Fig.	Ingot No.	Analysis of Carbide.			Corresponding to the Formula.	Theory.		
		Carbon.*	Iron.	Cobalt.		Carbon.	Iron.	Cobalt.
		Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
2	1492	7·18	90·88	1·94	$50\,Fe_3C + Co_3C$	6·66	91·41	1·93
		7·28	90·90	1·82				
3	1493	7·48	89·10	3·42	$28\,Fe_3C + Co_3C$	6·66	89·96	3·38
		7·35	89·36	3·29				
4	1500	7·54	86·47	5·99	$15\,Fe_3C + Co_3C$	6·65	87·23	6·13
		7·48	86·49	6·03				
5	1495	7·29	84·30	8·41	$11\,Fe_3C + Co_3C$	6·64	85·20	8·16
		7·32	84·68	8·00				
7	1496	7·00	82·20	10·80	$8\,Fe_3C + Co_3C$	6·63	82·50	10·87
		6·99	82·39	10·62				

* *See* Appendix (page 259).

Comparison of the Behaviour of Cobalt with Nickel in Steel.

The following comparison will be of interest, because nickel and cobalt have been commonly considered to be identical in their properties.

Chemical and Mechanical Comparisons.—Cobalt is not nearly such a great graphite precipitator as nickel. Cobalt steel ingots can be hammered down to 1 inch bars with only a very small separation

TABLE 6.

Plate 1. Fig.	Ingot No.	Cobalt.	Hammered Bars.		Annealed Bars.	
			Combined Carbon.	Graphite.	Combined Carbon.	Graphite.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2	1492	2·68	0·64	0·00	0·63	0·01
3	1493	5·50	0·62	0·00	0·16	0·46
4	1500	11·18	0·84	0·00	0·00	0·84
5	1495	16·97	0·93	0·00	0·00	0·93
7	1496	20·85	0·72	0·07	0·00	0·79

of graphite, 0·07 per cent. in the highest member of the series, containing 20·85 per cent. of cobalt.

In the case of nickel steel ingots treated in exactly the same way as the cobalt steel ingots, a small separation of graphite began with only 3 per cent. of nickel, and when 7 per cent. of nickel was present the precipitation of graphite amounted to about 42 per cent. of the total carbon.

Cobalt carbide appears, then, to be much more stable than nickel carbide, a conclusion which is also borne out by the analysis of the carbide residues obtained by electrolysis from cobalt and nickel steels respectively.

Cobalt does not form a definite solid solution or cobaltide of iron like that formed by nickel, having a composition corresponding to the formula Fe_7Ni, which, with only 0·1 per cent. of carbon present, registers a maximum stress of about 90 tons per square inch associated with a reduction of area of 45 per cent. An alloy containing about 13 per cent. of nickel and, say, 0·6 per cent. carbon is so hard that it is impossible to machine it,* whereas in the present series of cobalt steels, in which the carbon ranged from 0·62 to 0·93 per cent. and the cobalt from about 2·7 to 20·9 per cent., all the alloys, without any annealing, machined with the greatest ease. The hardness as measured by maximum stress seems with equal carbon to rise with the cobalt.

Micrographic Analysis.—The microstructures of the five hammered bars as received from the forge, also No. 1495 after annealing, are delineated in photomicrographs Figs. 2 to 7, Plate 1.

Photomicrograph Fig. 2, *Plate* 1.—Steel No. 1492, carbon 0·64 per cent., cobalt 2·68 per cent. This structure consists of cells of slightly cobaltiferous dark-etching pearlite with thick cell walls and irregular masses of yellowish-white cobaltiferous ferrite.

Photomicrograph Fig. 3.—Steel No. 1493, carbon 0·62 per cent., cobalt 5·50 per cent. The structure is very similar to that described for photomicrograph Fig. 2.

Photomicrograph Fig. 4.—Steel No. 1500, carbon 0·84 per cent., cobalt 11·18 per cent. The structure is of the same type as that presented by photomicrographs Figs. 2 and 3, except that the carbon being higher, the proportion of dark-etching cobaltiferous pearlite is greater and the quantity of pale-etching cobaltiferous ferrite is proportionally smaller.

Photomicrograph Fig. 5.—Steel No. 1495, carbon 0·93 per cent., cobalt 16·97 per cent. This structure consists almost entirely of dark-etching cobaltiferous pearlite, with a few ill-formed meshes and patches of pale highly cobaltiferous ferrite. Thus the saturation point of cobaltiferous pearlite seems higher than that of pure iron pearlite.†

* *See* Proceedings, I.Mech.E., March 14th, 1914, Table 14, page 263.

† *See* Appendix (page 259).

Photomicrograph Fig. 6.—Steel No. 1495 annealed. Combined carbon absent, graphite 0·93 per cent., cobalt 16·97 per cent. This structure consists of a ground mass of cobaltiferous ferrite showing faintly the junctions of allotrimorphic crystals and black masses of graphite.

Photomicrograph Fig. 7.—Steel No. 1496. Combined carbon 0·72 per cent., graphite 0·07 per cent., cobalt 20·85 per cent. In this steel the graphite has separated in a few widely distant areas, one of which is shown in the photomicrograph. The black graphite is embedded in the pale cobaltiferous ferrite. The main structure, in which no graphite was precipitated, consists of pale cell walls of cobaltiferous ferrite surrounding dark-etching cells of cobaltiferous pearlite.

Absorption and Recalescence Curves.—These will be dealt with in a separate Paper embodying the curves of all the steels used by the authors in their double-carbide researches.

In conclusion, the authors have to tender their sincere thanks to Mr. F. Amory Ruddock for his able help in the chemical branch of the research; to Mr. F. K. Knowles, B.Met., for his care in carrying out the mechanical tests; to Mr. F. C. Thompson, M.Met., B.Sc., for taking the photomicrographs; and to Mr. J. Harrison for his care in preparing the various test-pieces.

Finally, the authors would again respectfully thank the Council of the Institution of Mechanical Engineers for the "grant in aid" which has rendered this research possible. The research on the Carbides of Molybdenum may not be completed until the end of the war, because Professor Read and Mr. Ruddock are engaged on military duties.

The Paper is illustrated by Plate 1 and 1 Fig. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

Since reading the Paper the authors have gone carefully into one or two anomalous features in it, namely, that the carbon in the carbide averages about 0·7 per cent. above theory. Also that the photomicrograph Fig. 5, Plate 1, although containing 0·93 per cent. of carbon, is nevertheless unsaturated, cobaltiferous ferrite being obviously present. If the excess carbon be calculated to Co_3C, and the result added to the 5 or 6 per cent. yield, the latter is increased to 10 or 12 per cent., and if this be assumed to exist not as pearlite but as cobalt hardenite in solid solution, then micrograph No. 5 will only contain about 0·8 per cent. of carbon existing as iron pearlite, and to this the structure of the photomicrograph closely corresponds. It then follows that half the cobalt hardenite existing in solid solution has decomposed under electrolysis, the cobalt dissolving and the free carbon being left, with the main mixed mass of the iron and cobalt carbides forming the residue. The authors are of opinion that their new view is correct, and that the opinion expressed in the Paper on this particular point is not correct. Hence carbide of cobalt does not exist as pearlite, but in solid solution as hardenite in the mass of cobaltiferous ferrite. In this form it is much less stable under electrolysis than it would have been, could it have existed as pearlite.

The President, in calling upon Professor Arnold to read the Paper he had prepared in collaboration with Professor Read, said that Professor Arnold needed no introduction at the Institution. All the members were acquainted with the remarkable series of

(The President.)

researches which had been carried on in the Laboratory, which Professor Arnold had organized in Sheffield, which was a by-product of the large and important work he was also doing in instructing those who were to carry on the work of metallurgists in this country. Professor Arnold had taken the foremost place among Professors of Iron and Steel Metallurgy in the country.

Professor J. O. Arnold, before reading his Paper, stated that very little work had been done upon the element cobalt in connexion with metallurgy. As engineers, the members were no doubt familiar with an extensively advertised iridium high-speed steel made in Germany, in which, however, iridium was conspicuous by its absence. As a matter of fact, it was an application of the element cobalt to the highest type of British turning tool-steel, and the claim was made that by that addition the cutting properties of the best British high-speed steels were multiplied by 12. That was put forward on the authority of a certificate from Charlottenburg. Cobalt had thus been called very much into prominence, but in prolonged and careful researches which were made at the University of Sheffield they were unable, in the best type of British cutting high-speed steels, with cobalt ranging from 2½ to 11 per cent., to find any noticeable improvement. The Paper he was about to read had no reference to high-speed steel, but, as the title indicated, to the chemical and mechanical relations of iron, cobalt, and carbon. Tungsten, chromium, and vanadium were absent.

Discussion in London.

After reading the Paper,

Professor Arnold said he desired to be allowed to state that his co-author, Captain Read, who was a gunner, had been appointed Recruiting Officer for Glamorgan, where he had been most successful in his work, and the number of Welshmen he had induced to join the Colours had marked a record, he believed, for

Glamorgan. Mr. Ruddock, who had helped in the chemical branch of the research, was a private, but would possibly obtain a Commission, in the Sheffield University Battalion. As the Council had been good enough to place the remainder of the "grant in aid" in his hands without any restriction, he thought he would try to realize the "carry on" policy. He was glad to announce that it would be possible for that to be done, and he hoped to place the final Report of the researches in the hands of the Secretary in the autumn.

The researches had four branches: first, the metallurgical branch; second, the mechanical branch, and third, the micrographic branch. Those three branches had in the past always been carried out at the University of Sheffield. The fourth branch relating to the chemical part of the research had always been carried out at the University of Wales in Cardiff. He had been able to make arrangements with regard to molybdenum to transfer the chemical branch also to Sheffield. The research on the carbides of molybdenum steels was well advanced, and he thought the results would prove to be most interesting, as upsetting the preconceived idea that molybdenum closely resembled tungsten in its action on steel. It had been found in the course of the research that there were very important differences.

He also wished to explain that the work which the Institution had enabled them to carry out was to ascertain the double carbides existing in steel, particularly in alloy steels, and the molybdenum steels would be the last of the double carbides. In taking the various trenches, so to speak, which revealed the differential chemical composition of the carbides of single-element steels, namely, manganese, chromium, vanadium, tungsten, nickel, cobalt, and he hoped in the autumn molybdenum, they had cleared the ground in a manner which he hoped would enable them to take the citadel. That was, to find out exactly the component parts, and how they were combined in the mass, of the two standard types of high-speed steel which had enabled engineers to increase their output so greatly. Those two were the tungsten-chromium type and the tungsten-chromium-vanadium type, and such determinations would constitute

(Professor J. O. Arnold.)

a very difficult task. He was glad to be able to announce that his friend Sir Robert Hadfield considered the work so important that, in order to enable it to be carried out on the lines to which he had referred, namely, to ascertain the molecular characteristics of the two high-speed steels, he had very kindly supplemented the generous grant to the Institution with a further sum of £200. He desired publicly to thank Sir Robert Hadfield for his gift.

The PRESIDENT was sure the members would agree with him that the Institution had received a most interesting Report, for which he had very great pleasure in moving that the thanks of the Institution be presented to the authors. The return in knowledge which the members had gained was an ample reward for the small fraction of the Institution's income which had been expended in that way. It was rather curious that, as he happened to remark to Professor Arnold a little while ago, it seemed as if Great Britain had been kept at the head of the world in metallurgical research mainly by the requirements of the Army and Navy. The enormous demands for high-class material which had been made for guns, shells, and armour-plates had supplied the impetus, and probably the greater part of the funds, by which our credit as a metallurgical nation had been maintained in its very high place.

The resolution of thanks was then put, and was carried with acclamation.

Sir ROBERT A. HADFIELD (Member of Council), in opening the discussion, said he was sure all the members would agree that they were much indebted to the authors for putting before them the very important results that had been obtained from the valuable research they had carried out. As far back as 1891 he (Sir Robert) first made a study of the effect of the metal cobalt when added to iron. The reason that research was then carried out was that a few years previously he had read a Paper before the Institution of Civil Engineers on the effect of manganese alloyed with iron, the results of which had proved of such a startling nature, quite upsetting the

then prevailing ideas as to what had hitherto been termed steel, that it was thought desirable to see the effect of other elements when added to iron. Consequently he carried out a series of important researches relating to the influence of silicon, aluminium, chromium and tungsten, and then the sister metals in the same group as iron, namely, nickel and cobalt. He first undertook the study of iron and nickel, the Paper regarding which was not, however, presented to the Institution of Civil Engineers until 1899. As cobalt was the sister metal of nickel, he then carried out a research with regard to its effect upon iron. Although the specimens now referred to were produced in 1891, and were exhibited at the Science Section of the Literary and Philosophical Society in Sheffield a short time afterwards, no other public reference was made to the research until the short Paper he gave to the Engineering Conference of the Institution of Civil Engineers, Section IV, "Mining and Metallurgy," held on the 26th May 1897. That was further followed up by a complete set of records being presented by him to the American Paper, *The Iron and Steel Metallurgist and Metallographist*, in 1904, in which full reference was made to the research in question. He only referred to the historical side of the question, because he thought it desirable it should be placed on record where the facts were really first presented.

The alloys of cobalt and iron might some day be very important, and he would refer to one of them a little later on in his remarks. Naturally the use of cobalt, even if it had been available, was practically prohibitive because of its enormous price. The cost of the cobalt used in his experiments made in 1891 was no less than 29*s.* per lb., so that the members could quite appreciate that the production of cobalt steel commercially was not very attractive, even if it presented great advantages. In those particular cobalt alloys the base used was mild steel containing about 0·20 per cent. carbon. Specimen "A" given in Table 1 (page 248) in the Paper represented the physical properties of that mild steel. When annealed, it gave an elastic limit of 20 tons per square inch, a breaking load of 31 tons per square inch, an elongation of 35 per

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cent., and a reduction of area of 46 per cent. Its full analysis was given in Table 1 (page 248). At that time aluminium and elements of that kind were not available. It was possible, it was true, to use silicon, and it was necessary to use large quantities of silicon to obtain soundness. The specific gravity of that alloy was 7·75. That was entirely consistent with the analysis given, and was what would be expected with a breaking load of about 31 tons with very considerable elongation. That was the base—that is, all the subsequent alloys to which he referred were made with mild steel of that composition, to which was added cobalt in various percentages. Specimens B to F contained gradually increasing quantities of cobalt, the percentages arrived at being 0·50 in B, 1·80 in C, 2·50 in D, 4·50 in E, and 6·90 in F. He thought he had there gone as high as he would care to go, because it did not seem to him that any other characteristics of value would be found, and seeing the enormous expense of the alloy, he did not investigate further. The authors, however, had gone much higher and made a very interesting further research on alloys of cobalt and iron with higher percentages.

He (Sir Robert) found that with 0·50 per cent. of cobalt he obtained 22 tons elastic limit, 31 tons breaking load, and about the same percentage of elongation and reduction of area as in the steel containing no cobalt, so that evidently there was no special advantage in adding cobalt. It was practically the same as the mild steel which formed the base. It might be interesting to state that the ball hardness was about 170 in the unannealed condition, and when thoroughly annealed 125. In the next percentage, 1·80, a very considerable increase was obtained, the unannealed specimen rising to 41 tons breaking load and 19 per cent. elongation. He also took the relative specific resistance of that particular specimen, and found it was 27·3 microhms against 12 microhms in pure iron. In the next specimen, in which there was 2·50 per cent. of cobalt, the breaking load went up to 52 tons, with 38 tons elastic limit, elongation 15 per cent., and ball hardness of 228 unannealed, and 170 in its annealed condition. With 4·50 per cent. cobalt a breaking load of 57 tons was obtained, 15 per

cent. elongation, and a ball hardness of 239 on the unannealed specimen. The annealed specimen had 25 tons elastic limit, 46 tons breaking load, 19 per cent. elongation, but only 22 per cent. reduction of area, and a ball hardness of 185. In order to see the effect of the toughening treatment, a specimen of the same material was taken a few months ago, quenched in oil at 830° C., reheated and quenched in water at 615° C. An elastic limit was then obtained of 44 tons, a breaking load of 64 tons, an elongation of 10 per cent., and a ball hardness of 274. There was no special advantage in the alloy because it was not particularly tough, and it possessed no special characteristics making it of any commercial value. In specimen "F" 6·90 per cent. of cobalt was used, and it gave not very different results from specimen "E." The specific

TABLE 7.

Copy of Hadfield Experiment on Cobalt, 13*th May* 1891.

Experiment No. 1209.

The Cobalt used was obtained from Messrs. Johnson Matthey and Co., London. Its cost was 29*s*. per pound.

The base employed for each alloy was Mild Steel of the composition shown by specimen "A," which of course contains no Cobalt.

Analysis, per cent.

—	A	B	C	D	E	F
Carbon	0·20	0·16	0·25	0·38	0·55	0·52
Silicon	0·64	0·61	0·64	1·21	0·65	0·79
Sulphur	0·10	0·10	0·11	0·14	0·11	0·14
Phosphorus . . .	0·06	0·07	0·07	0·07	0·06	0·06
Manganese . . .	0·80	1·04	1·04	0·65	0·79	0·79
Nickel	—	Nil	Nil	—	—	—
Cobalt	Nil	0·50	1·80	2·50	4·50	6·90
Specific Gravity .	7·75	7·681	7·653	7·692	7·656	7·778

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The following were the mechanical tests:—

TABLE 8.—*All tests were cut from forged bars $1\frac{1}{4}$ inch diameter.*

—	Treatment.	Co.	Tensile Test. E.L.	Tensile Test. B.L.	Tensile Test. E.	Tensile Test. R.A.	Shock Tests. "C" Nick. Kgm.	Shock Tests. "C" Nick. Angle.	Shock Tests. No Nick. Kgm.	Shock Tests. No Nick. Angle.	Ball Test.	Resistance Tests.	Specific Resistance Microhms.	Specific Magnetism.
		Per cent.	Tons.	Tons.	Per cent.	Per cent.	Kgm.	Angle.	Kgm.	Angle.		Fe=100.		Fe = 100.
A	Unannealed	Nil	27	37	24	28	—	—	—	—	—	—	Pure Iron. 12	—
	Annealed		20	31	35	46	—	—	—	—	—	—		—
B	Unannealed	0·50	27	38	29	43	5·0	14°	38	120°	170	—	—	—
	Annealed		22	31	34	47	3·4	14°	33	114°	125	—	—	—
C	Unannealed	1·80	25	41	19	23	—	—	—	—	—	40·6	27·3	—
	Annealed		23	35	29	39	—	—	—	—	—	47·7	23·2	98·6
D	Unannealed	2·50	38	52	15	15	1·0	Nil	24	58°	228	—	—	—
	Annealed		27	43	14	24	0·2	Nil	7	18°	170	—	—	—
	Annealed	**2·68**	**29**	**48**	**17**	**26**	—	—	—	—	—	—	—	—
E	Unannealed	4·50	37	57	15	17	1·3	2°	20	39°	239	—	—	—
	Annealed		25	46	19	22	0·5	3°	13	32°	185	—	—	—
	830° O. 615° W		44	64	10	9	0·8	$1\frac{1}{2}$°	10	30°	274	—	—	—
	Annealed	**5·50**	**33**	**48**	**22**	**42**	—	—	—	—	—	—	—	—
F	Unannealed	6·90	39	55	13	13	2·2	2°	22	49°	223	33·0	33·6	—
	Annealed		30	44	22	25	0·4	1°	12	30°	179	36·1	30·7	98·9

The figures in heavy type represent Professor Arnold's specimens, containing nearly the same percentage of Cobalt.

resistance of that particular specimen was 33·6 microhms as against about 12 microhms in pure iron. If the authors could make a few electrical resistance tests on his specimens, he thought it would be very interesting and would make the series more complete. He thought Professor Arnold would find that, as the cobalt went up, the resistance would increase just in the same way as if a nickel iron alloy were being made. Tables 7 and 8 were those referred to in the above remarks.

It would be noticed that the series of experiments he had referred to did not go higher than about 7 per cent. cobalt. It was also aimed to keep the carbon down, though not in all cases. He was not very successful in that respect in some of the higher specimens, in which the carbon should have been 0·20 per cent. but went up to about 0·60 per cent. Professor Arnold, on the other hand, with his alloys, aimed at a fairly constant percentage of somewhat higher carbon, and the specimens nearly all contained 0·60 per cent., a much more uniform series of tests being obtained. It might be interesting to state that the tensile strength of cobalt in its cast condition was about 15 tons per square inch in either the unannealed or annealed condition, and its fusion or melting point was about 1,470° C. The results of the tests generally showed that cobalt, like nickel, considerably increased the elastic limit and breaking load; in fact, it seemed somewhat superior in that respect. He was, of course, only speaking with regard to the percentages tested by him, up to 7 per cent., so that he could not say anything further about it. A comparison of mechanical tests obtained from the cobalt and nickel steels was shown in Table 9 (page 268).

The results obtained by the authors confirmed in the main the results of his own experiments in 1891, namely, that cobalt in its general action resembled that of nickel in raising the elastic limit and breaking load of the material. He could fully confirm the authors' remarks that the annealing of cobalt steel must be done very carefully or there would be precipitation of graphite. He also agreed with Professor Arnold when he said that cobalt did not form a definite solid solution or cobaltide of iron like that

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formed by nickel. It was very curious that nickel and cobalt seemed to throw out the carbon.

At one time he (Sir Robert) was particularly anxious to ascertain whether it was not possible to obtain what he might call an "imitation steel." If carbon could be added to iron forged,

TABLE 9.

Specimen Mark.		Unannealed Test-Bars.				Annealed Test-Bars.			
		E. L.	B. L.	E.	R. A.	E. L.	B. L.	E.	R. A.
		Tons.	Tons.	Per cent.	Per cent.	Tons.	Tons.	Per cent.	Per cent.
B	Cobalt 0·50 .	27	38	29	43	22	31	34	47
B	Nickel 0·50 .	20	30	36	62	21	27	41	63
C	Cobalt 1·80 .	25	41	19	23	23	35	29	39
D	Nickel 1·90 .	26	34	33	55	22	31	36	53
D	Cobalt 2·50 .	38	52	15	15	27	43	14	24
E	Cobalt 4·50 .	37	57	15	17	25	46	19	22
F	Nickel 5·80 .	28	41	27	40	28	37	33	51
F	Cobalt 6·90 .	39	55	13	13	30	44	22	25
G	Nickel 7·60 .	31	49	26	42	30	45	26	41

heated to, say, 750 or 800° C., quenched in water, and a hard compound obtained, if nickel was in the same group, why should it not be possible to add carbon to nickel, because it was in the same group as carbon and cobalt? He tried that over and over again, hoping to startle the world with what might be termed a false steel—that was to say, a steel in which there was no iron present,

and yet which had the properties of iron. But he could not succeed, for the very reason, as Professor Arnold had pointed out, that when carbon was present, as soon as it was heated, graphitic precipitation took place, and consequently it was impossible to get iron. That was a very wonderful fact, because it showed that after all their old friend iron was the only metal in which, up to date at any rate, it was possible to combine carbon and obtain a malleable compound that could be forged and treated, and then by heat treatment subsequently hardened, by means of which all those valuable compounds were obtained which were so absolutely necessary for the world's existence at the present day. If the property of not being able to harden what was called carbide of iron, the compound of iron and carbon, was taken away, mechanical engineers would cease to exist, because it would be almost impossible to machine anything. Certain substitutes would be found, but he thought they would be very poor ones. That all turned on the wonderful fact that iron and carbon in certain conditions would harden, so that a cutting edge could then be obtained. It showed, therefore, it was not well to generalize that, because the two metals cobalt and nickel were in the same group, and had several similar properties, their effect upon iron should be the same.

Iron was the most mysterious metal known. It was therefore never safe to theorize about new alloys; they must be made, and their nature and qualities most carefully examined before one was able to draw more definite conclusions. He thought in that respect those in Sheffield engaged in researches of such a nature had fully realized that, abroad, particularly in Germany, most extraordinary results had been put forward on theoretical assumption without obtaining the definite facts, or starting with correct data. Several researches presented by Germans had been particularly misleading in that respect. However much in the past their patient experimental methods might have been admired, the conclusions drawn had often been quite wrong. For example, experiments had been made in Germany with regard to the addition of cobalt to high-speed tool steel. They were trumpeted as a great

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discovery, but his friend, Professor Arnold, undertook a very elaborate series of research tests for Sheffield, with the result that, taking into consideration the extremely high cost of cobalt, the advantages gained were not worth the expense incurred.

He would like to say a few words with regard to the splendid work Professor Arnold had done for his city. Sheffield gained its first reputation on what might be termed "rule of thumb" work. To-day there was no city or district which could beat, or, he thought, compare with the valuable work done there, not only from the point of view of pure or research science, but in the application of science to the practical requirements of industry and commerce. For that happy combination Sheffield, and the Empire generally, was largely indebted to his friend, Professor Arnold, who had done so much to keep this country to the front, not only by the value of the researches carried out under his direction, but also by happily keeping them out of the pitfalls into which scientists in metallurgy elsewhere had fallen. He referred, for example, to Sheffield having avoided the serious pitfall of allotropy, the study of which, whilst it had, he admitted, led to good research work and general discussion which had proved of benefit, had in the past seriously misled some of the younger men in this country, who, to their disadvantage, had had to unlearn those particular theoretical considerations. He would like to emphasize, especially at the present time during the stress of war, the immense advantage of having a local University with its Applied Science Department, its Scientific Advisory Committee, and other bodies, all helping to keep us in the true lines of accuracy and progress.

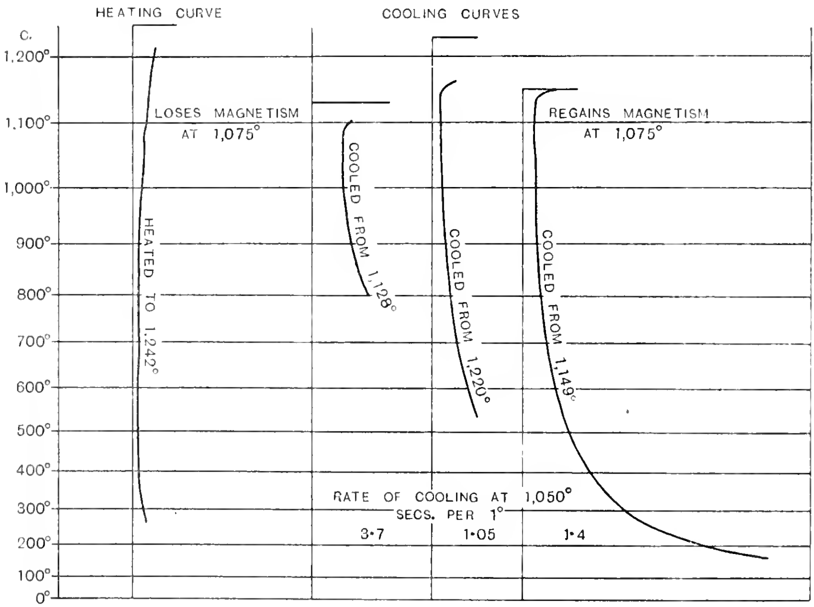
It might be of interest to add that he (Sir Robert) had carried out some experiments to find what was the temperature at which the magnetic change-point of cobalt took place. Cobalt had certain magnetic change-points, just like iron and nickel, but each of the three elements was totally different. The first test seemed to show that that change-point occurred between 1,000° C. and 1,200° C. Nickel, on the other hand, had magnetic changes at 340° C., so that in that respect there was considerable difference between the two metals. Further tests were made later on as

follows: A specimen of cobalt was placed in a small clay crucible and heated in the injector furnace. The temperatures were taken by thermal-couple in intimate contact. The magnetic state was tested by an ordinary hand-magnet. That might seem a rough

Fig. 8.

Cobalt (metal), containing 0·41 *per cent. C. Curves taken by "Inverse Rate" Method.*

The curves are plotted from observations of the temperature and time, by the Osmond method.



method, but it was a fairly accurate one. The results obtained were practically concordant, the magnetic change-point being found to be 1,075° C., that being the same either for heating or cooling. The results of those tests were shown in Fig. 8.

Somewhat singular to say, the change-point at 1,075° C. either on heating or cooling did not appear to be indicated by any change-point on the curve. That was rather singular, and it was probable that if Professor Arnold would undertake an investigation with his

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very delicate and sensitive instruments, he might be able to find some change in the curve, but so far he (the speaker) had not been able to detect any. The above experiments were made only about twelve months ago.

On referring to some old experiments, he found that in 1893 they obtained very similar results—that is, cobalt was strongly attracted below about 1,080° C. The cobalt sample tested could not be forged from a high yellow temperature, say about 1,150° C. The electrical resistance of specimens "C" and "F" referred to in the joint Paper by Professors Barrett and Brown and himself

TABLE 10.

Iron Alloyed with	Specific Resistance of 1 per cent.	Specific Heat.	Atomic Weight.
Tungsten . . .	1·1	0·035	184
Cobalt . . .	2·2	0·107	59
Nickel . . .	2·5	0·109	59
Chromium . .	3·0	0·1 (?)	52
Manganese . .	5·2	0·122	55
Silicon . . .	10·3	0·183	28
Aluminium . .	11·1	0·212	27

(Sir Robert) were as follows:—Specimen "C" contained 1·80 per cent. cobalt; with iron as 100, the resistance was 44, or as compared with copper 100, the resistance was 7·4. Specimen "F," containing 7 per cent. cobalt; with iron as 100, the resistance was 33, or as compared with copper 100, the resistance was 5·6. The specific resistance was, for specimen "C," 23 microhms, for specimen "F," 31 microhms; and for pure iron it was about 12 microhms. As was well known, so far it had been found that all elements added to iron increased the electrical resistance. Tungsten produced the least effect, namely, for each 1 per cent. an increase in specific resistance of 1·10 per cent. Aluminium was

the highest, namely, 11·1 per cent. Cobalt, next to tungsten, had the least effect—that was, for each 1 per cent. an increase in specific resistance of 2·2 per cent., nickel 2·50 per cent., chromium 3·00 per cent., manganese 5·20 per cent., and silicon 10·30 per cent. It might be mentioned that those increases of resistance occurred as the specific heat increased. For example, the specific heat of tungsten was 0·035, and the atomic weight 184; the specific heat of aluminium was 0·212, and its atomic weight 27. That was given in Table 10, which would probably be of interest, as he believed it had not been commented upon by those who had made researches in that direction.

It was very curious indeed to note that, as the atomic weight went down, the specific resistance went up, and as the specific heat went up the specific resistance also went up. It would be noted that he commenced with tungsten and went on to cobalt, nickel, chromium, manganese, silicon, and aluminium, and it was very curious to find that those alloys followed some definite law. They did not at present understand that law, but they were little by little and year by year getting more knowledge on that particular subject. The only exception which was found in the joint research referred to was that of chromium, the specific heat of which element was at that time somewhat doubtful. He had not looked up the point since, but he believed it had fallen into line. As pointed out in the Paper he had mentioned, that remarkable correspondence shown in the Table given appeared to be more than a chance coincidence. If it should prove to be a real physical relationship, some light might be afforded on the obscure question of what determined the remarkable increase in resistance when a comparatively good conductor like aluminium was alloyed with iron. If the best conductor in the world, aluminium, was alloyed with iron, the worst possible conductor was obtained—a very curious result. It might also be of service to add, with regard to specimens "C" and "F," that whilst those alloys contained somewhat high carbon, also some silicon, after allowing for the effect of that impurity upon the conductivity, the cobalt curve was found to lie close to the nickel curve—that was, on the tungsten side of it. In other words, as he had pointed

(Sir Robert A. Hadfield.)

out, the increase in specific resistance produced by cobalt appeared to be rather less than that caused by nickel, but still considerably more than that by tungsten, which had some bearing upon its value in connexion with high-speed tool-steel. He was sure they would all be glad if Professor Arnold would give them the benefit of his opinion on that point. He had never seen any satisfactory explanation offered. It certainly looked as if it were the tungsten or the tungstoid of iron to which the author referred in the previous splendid Paper he gave to the Institution a year ago. He very much regretted that he (Sir Robert) was in America at the time, so that it was not possible for him to attend. Some of the members might not see the advantage of studying those particular alloys, but at the bottom of it all they were accumulating by degrees important information which enabled them to understand more that very wonderful metal, iron.

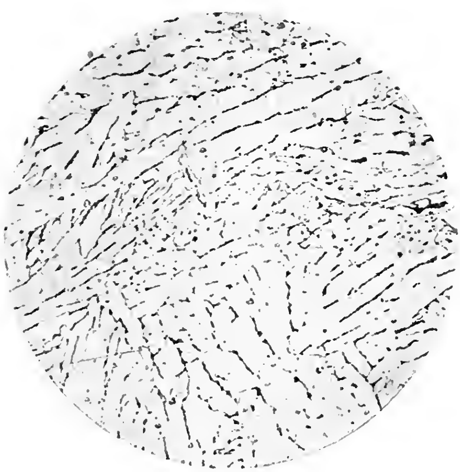
In conclusion, it might be interesting to refer to the fact that Professor Weiss, whose very able work during the last few years would in the near future probably be found of the greatest value to the metallurgist, had shown that iron-cobalt alloys containing 33 per cent. of cobalt and about 66 per cent. of iron, termed by him super-magnetic cobalt alloys, possessed 10 per cent. greater specific magnetism than the purest iron known. In other words, we had an alloy here which was positively better than pure iron itself. A small bar was tested in the Hadfield laboratory and gave the following results :—

	Saturation Magnetism.	
	Per Unit Weight.	Per Unit Volume.
Iron-cobalt Alloy	107·2 to 107·5	108·3
Pure Iron	100·0	100·0

This alloy was melted in an electric resistance furnace. Its fracture was coarse, bright crystalline, and not very sound. The exact analysis was as follows:—

Carbon.	Cobalt.	Iron.
Per cent.	Per cent.	Per cent.
0·10	33·00	(about) 66·00

Fig. 9.—*Iron-Cobalt Alloy.*
× 70 diams.



Its specific gravity was 1·01 compared with pure iron 1·00. The specimen had a ball hardness number of 218, and was very brittle. One half of the shock-test piece when heated to a dull red forged well from this temperature up to about 1,000° C.; above this temperature it crumbled. The microstructure was shown by the photomicrograph, Fig. 9, taken at 70 magnifications. The following is the description of the structure:—

A white ground-mass was covered with microscopic cracks which in some cases appeared under a low power to be continuous, but which

(Sir Robert A. Hadfield.)
on higher magnification proved discontinuous. On each side of portions of a crack were very fine lines like the dashes of the pen that a black and white artist used for shading. The whole structure suggested a lack of cohesion. Pearlite was present in elongated crystals running in different directions in different groups. The crystals in the same group ran parallel to each other, and small globules of sulphide were present.

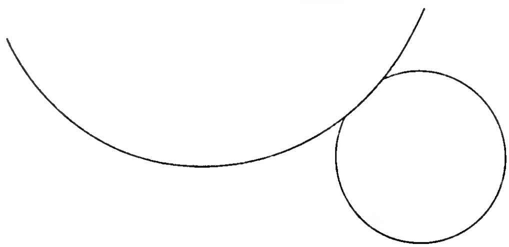
In the above there was no clue to the reason why this alloy possessed higher magnetic values than pure iron. Its superior magnetic qualities could be tested by a small hand-magnet, which would lift much larger lumps of the iron-cobalt alloy than compared with pure iron. This alloy, as Professor Weiss had pointed out, should be of considerable advantage for special electrical apparatus and pole pieces of electro-magnets, also electrical machinery, and in the construction of laboratory electro-magnets, dynamos, electro-magnetic brakes and for other purposes.

Mr. EDWARD BATTEN desired to emphasize the fact that metallurgical researches were of more direct use to the ordinary machine-maker and engineer than anything else to which scientific bodies could direct their attention; because whilst it was no doubt the fact that the common sense of engineers would carry them a long way in regard to the proper application of metals, once they had obtained the necessary experience, he knew of nothing in which they found themselves so helpless as when the ordinary engineer was asked to attack some new problem that depended upon the ability of metals to stand up under stresses which, in the whole course of his experience, he had never seen applied to such metals before. He felt compelled to join in the discussion because, when he was in America about twelve months ago, he was asked by the firm for whom he was working whether it would not be possible to get a metal which would stand a certain big strain. Steel, as a matter of fact, was referred to.

Fig. 10 indicated a large drum 6 ft. in diameter, in contact with which was an endless steel tube that had a reverse bend of about 4 inches. Both the drum and tube rotated in contact at the same

surface velocity. The size and the thickness of the tube were immaterial, but it was desired to know whether it were possible to have such an operation carried on with metals. He replied that he did not know, and he recommended those who made the inquiry to consult the Bethlehem Steel Co., and ascertain what their experience led them to think on the matter. This firm, however, was too busy to make the experiment. He came back and tried to solve the problem by brazing up all sorts of metals, but he found they all failed at the joint. Eventually he had some hoops made by the Bethlehem Steel Co. of the character described, but unfortunately Dr. von Philip (their technical expert) had more faith than was justified. The thinnest hoop that he made was $\frac{1}{10}$-inch thick, and

Fig. 10.—*Flexible Roller.*



the result obtained was not altogether satisfactory. They lasted, however, longer than any jointed tubes. He was still endeavouring to find a grade of metal that would best suit the purpose, and the only way in which he thought it was likely to be found was by such investigations as were carried out by the authors, because no one at present seemed to know the characteristics for a metal that would stand such a stress indefinitely. Up to the present, copper was better than iron, but whether that was due to the facility of being able to produce a very thin tube of copper compared with that of iron he did not know.

Mr. R. H. Greaves (Cardiff) said he had been very much struck by the results of the carbide experiments, because he had had the privilege of seeing most of the later work that had been done at

(Mr. R. H. Greaves.)
Cardiff. He was exceedingly interested to hear the remarks Sir Robert Hadfield and Professor Arnold had made in regard to cobalt in high-speed tool-steel, because it was very difficult to obtain information on that subject. The small proportion of cobalt carbide in the mixed carbides of the steel did not lead one to suppose that cobalt would have a very powerful influence in that direction. He had been much interested in the conclusion of the research, for the reason that if the elements were written down in the order of their atomic weights according to the periodic law, a series was obtained in the neighbourhood of iron like the following, Table 11: vanadium,

TABLE 11.

V.	Cr.	Mn.	Fe.	Co.	Ni.	Cu.
Replaces iron completely, forming single carbide V_4C_3.	Replaces some iron, forming stable double carbides.	Double carbides. Less stable.	—	Mixture of carbides.	Mixture of carbides. Less stable.	No carbide.
Properties modified, chiefly by carbide.	Properties modified, chiefly by carbide.	Hardness due to carbide. Toughness due to metal.	—	Effect of carbide less.	Ni metal, Fe_7Ni the chief influence.	Cu metal, the only influence.

chromium, manganese, iron, cobalt, nickel, and the first element in the next class was copper. They were the fifth, sixth, seventh, eighth, and first group respectively. It was curious to notice that all those elements had been examined by the authors with the exception of copper, which was well known not to form any carbide, so that there remained vanadium, chromium, manganese, cobalt, and nickel. The Report thus formed the conclusion of that series of elements lying on each side of iron. Strictly speaking, the atomic weight of nickel was intermediate between iron and cobalt, but the periodic system was always written in the form: iron-cobalt-nickel, and not iron-nickel-cobalt, because nickel was well known to be allied to copper more than the cobalt was. The order iron-cobalt-nickel was justified by the results of the carbide researches.

In dealing with the question of the stability of carbides, Professor Arnold had pointed out that nickel was the greatest graphite precipitator. Fe_3C was the most stable; CO_3C was the next, and Ni_3C was the least stable on annealing. Professor Arnold further remarked that Co_3C was more stable than Ni_3C during electrolysis in the presence of acids, so that the same order was obtained, Fe_3C being the most stable, Co_3C being the next stable, and Ni_3C being the least stable. If the question of the amount of carbon with which each of those elements combined was considered, the nickel results of Professor Arnold showed that, with 7·1 per cent. of nickel in the steel, 1 molecule in 30 of the mixed carbides was Ni_3C, and with the smaller quantity of 5·5 per cent. in the case of cobalt, the same proportion, 1 in 29, or roughly 1 in 30 of the mixed carbides, was present as cobalt carbide. It appeared, therefore, that the affinity for carbon in the case of cobalt was greater than in that of nickel, which also confirmed the order, iron-cobalt-nickel. Taking the full series, it was found that vanadium replaced the iron completely in the carbide and formed a single carbide, V_4C_3; chromium partially replaced the iron and formed a very stable or several stable double-carbides; manganese partially replaced the iron and formed double-carbides not so stable.

Going on to cobalt on the other side of the iron, it was found there was a mixture of carbides. There was a similar mixture of carbides with nickel but not so stable, and in the case of copper there was no carbide. From vanadium through iron to copper there was a gradual transition from an extremely stable single-carbide through stable double-carbide to less stable double-carbides, thence to a mixture of carbides, and finally to no carbide at all. To go over the same ground again, the influence of those elements on the properties of the material in the case of vanadium was mainly due to the carbide; in the case of chromium it was mainly due to the carbide; in the case of manganese there was a sort of double influence, a hardening influence due to carbide and a toughening influence due to the manganese metal.

Passing on to the other side, in cobalt the influence of the carbide was less; in nickel it was entirely overwhelmed by the influence of the metal, and the nickel exercised its most powerful

(Mr. R. H. Greaves.)

influence in combination with iron, as either a definite solid solution or a compound of that kind. In the case of copper the influence of the carbide had vanished, and the modification of the properties due to the addition of copper appeared to be entirely due to the influence of metallic copper.

Several years ago the late Sir William Roberts-Austen, in a Report read before the Institution, attempted to classify the hardening elements on the basis of their atomic volumes. Nobody had done more important work showing that that classification was unjustifiable than Professor Arnold, who had stated in his Report, read last year, that every element was a law unto itself. In the present case, however, it seemed that there was a certain amount of order; that although they might be a law unto themselves, there was a certain transition on passing from one element to another; and it was very satisfactory to find that a research which was intended to elucidate the chemical as well as the mechanical influences of those elements in steel led to some results which seemed to be correlated on the basis of the periodic system.

Professor ARNOLD, in reply, desired to thank the President for the very kindly terms in which he had moved the vote of thanks, and the members for the cordial manner in which they had passed it. The discussion, which had perhaps been of a nature a little out of place at the Institution, although he did not think it should be, had taken a more favourable turn than could have been expected, and some very interesting points had cropped up. He was very glad to hear Mr. Greaves' remarks, because he was the first research assistant of Professor Read and himself at Cardiff, his place being occupied until recently by Mr. Ruddock, the assistant with whom the Institution provided them. The case brought forward by Mr. Batten was a most remarkable one, because the only characteristic mechanical property of copper that stood out was the fact that it had practically no elastic limit. Whether that might account for its extraordinary superiority over steel in the case that had been described by Mr. Batten he did not know, but that was the only suggestion he could make.

In replying to some of the points that had been made by his friend, Sir Robert Hadfield, he did not think he (the author) had previously pointed out that one result of the researches had been to show that there were three true steels. There was, first of all, the old iron and carbon steel; a soft steel which transformed to hard steel; or hardenite, at about 730° C. over an amplitude of temperature of 3°. But the result of the researches carried out under the auspices of the Institution had given two other true steels, for the following reason. On adding vanadium to the extent of 5 per cent. to true iron and carbon steel, the carbide of iron ceased to exist; it was expelled. An absolutely new steel was obtained, a true vanadium steel, in which no carbide of iron existed, but carbide of vanadium which formed soft vanadium pearlite. It was most remarkable, however, that instead of transforming to vanadium hardenite at 730° C., it could only be made to transform just before the melting point of the steel, about 1,450° C. Thus a turning tool was obtained as hard as corundum, unfortunately too hard to be of any practical use, because it snipped in the lathe; but it was far harder than the ordinary carbon tool. Then taking the case of tungsten, at 11·5 per cent., tungsten expelled the carbide of iron, and a true tungsten steel was obtained. The transformation of the tungsten pearlite in the soft state to the tungsten hardenite in the hardened condition was a most remarkable one. Instead of taking place over an amplitude of 3°, commencing at about 728° C. and ending at about 731° C., as an ordinary carbon turning tool did, the transformation started at about 850° C., and the hardness was not completed until nearly 1,200° C., so that they were actually face to face with three tool-steels, and in connexion with the hardening of steel no general law of hardening could be laid down which did not take into consideration the hardening of those three distinct steels. The hardness must be determined, more or less, to the same law, and in order to ascertain that law, it was necessary to consider the hardening properties of the whole three of them.

In connexion with the hardening of steel, the taunt was often thrown at them that when a piece of tool-steel was quenched they

(Professor J. O. Arnold.)

did not know why it was hard. He quite admitted that statement, but on the other hand they did not know why a diamond was hard, or why corundum was hard, or why quartz was hard. The question to be answered was not why steel was hard—that was a broad general academic question which applied to all hard minerals—but what engineers wanted to know was how it was hardened, and the manner in which it hardened, so that the engineer and the metallurgist could treat it in the proper way. That was an important point to bear in mind.

In connexion with the suggestion he ventured to put forward in the last Report, that each element must be investigated on its own merits, and every inch of the ground gone over, one eminent engineering journal, in commenting on the suggestion, styled it "The New Metallurgy." He rather objected to the statement. Personally, he thought it was the old metallurgy. It was the metallurgy of Tubal-Cain. He did not know whether there were any civil engineers in existence at that time, but at any rate, so far as mechanical engineers were concerned, if Tubal-Cain had not supplied them with what was wanted, he would have soon known about it. He thought the metallurgy of Tubal-Cain was coming in again, because it was a very simple metallurgy, namely, in connexion with the testing of steel, the correlation of the work of the metallurgist and of the mechanical engineer.

The PRESIDENT announced that Professor Arnold had kindly consented to attend a Meeting of the Institution in the Rankine Hall, Glasgow, by permission of the Institution of Engineers and Shipbuilders in Scotland, on Thursday, 8th April, when the Paper would be again read and discussed.

Communications.

Dr. W. H. Hatfield (Sheffield) wrote that he would like to congratulate the authors upon the publication of this further addition to this series of Papers. The published data on the influence of cobalt was undoubtedly scanty, and the present Paper contained the results of experiments which considerably extended one's knowledge of the subject. The outstanding feature was undoubtedly the difference existing, as the authors pointed out, between the influence of nickel and that of the element under discussion. The same comparison could be made in the case of manganese. If the iron-nickel, iron-manganese, and iron-cobalt systems were compared, it would be found that the phenomena presented were fundamentally different. In the instances of both manganese and nickel, the increasing addition of these elements to the iron resulted in the magnetic change being not only lowered but also made irreversible, and in each instance the high tenacity synchronized with the range in which this tendency was approaching towards its maximum. On the other hand, it would be found that the addition of cobalt to iron raised the temperature of the magnetic change. It would therefore probably be anticipated that such a profound difference would, as the authors had found, be reflected in the influence of cobalt upon the general physical properties of steel. It was therefore certain that the recalescence phenomena of the whole of the alloys treated by Professors Arnold and Read would be of additional value, and that the Report containing them, which they promised for the near future, would be appreciated.

The data relative to the comparative influence of cobalt upon the stability of the carbide under heat-treatment were very interesting. As regards the authors' deduction that the cobalt was present in the carbide as cobalt carbide, might this not be reasonably questioned after the consideration of the work by Beck to which they referred? Was it not possible that the cobalt was in solid solution, and was thus responsible for the carbide being rendered less stable during the electrolytic treatment? The presence of the high percentage of

(Dr. W. H. Hatfield.)

carbon in the residue, coupled with the fact that the percentage of the cobalt present therein did not increase with the cobalt content of the steel, would rather appear in his (Dr. Hatfield's) mind to point to this.

Professor Arnold, in reply to Dr. Hatfield's Communication, wrote that he had really dealt with the perfectly valid criticism of that gentleman in the Appendix (page 259), which Dr. Hatfield had not yet seen. He would find that the authors had come to very much the same conclusion as Dr. Hatfield, and that, as a matter of fact, as in the case of nickel there was no nickel pearlite, so in the case of cobalt there was no cobalt pearlite but only cobalt hardenite in solid solution. The authors much appreciated the value of Dr. Hatfield's remarks.

Meeting in Glasgow.

The Report on the "Carbides of Cobalt" was read and further discussed in the Rankine Hall, Glasgow, by permission of the Institution of Engineers and Shipbuilders in Scotland, on Thursday, 8th April 1915, at 8.0 p.m. Dr. Archibald Barr, *Member of Council*, presided, and 40 Members and Visitors were present.

The Chairman, in introducing Professor Arnold, remarked that, while this Meeting had been announced to the various local Institutions, they were met under the auspices of the Institution of Mechanical Engineers. Several years ago the Council of the Institution proposed a scheme by which, on a desire being expressed by the members resident in any district, a Paper read before the Institution in London could be re-read and re-discussed in that

district. It had not seemed necessary for them to hold such meetings in Scotland before this time, but he was certain that the occasion had arisen when they could have Professor Arnold with them to read this interesting Report. They as engineers—if he might speak to those of them who were engineers as distinguished from metallurgists—were, he thought, a little too apt to look for immediate results from the investigations of those other scientific men of other professions who were paving the way for them. This reminded him of a celebrated man, who, when some one asked the use of a new scientific discovery, said: "What is the use of a baby?" And answered it by saying: "He may become a man." So it was with investigations such as that to be dealt with there that night. They could not foresee what the results of these investigations might mean a few years hence, and therefore all of them, whether metallurgists or engineers, should be thoroughly interested in any investigations of this kind; and he thought, as engineers again, they ought to be very thankful indeed to the sister profession of metallurgy. At the present time there was no science that was making more rapid progress than that to which Professor Arnold belonged. He was afraid, however, that most engineers were under a disadvantage in considering such Papers as that to be brought before them. The progress in metallurgy had been so rapid that, with all their other engagements and interests, they had not been able to follow it as they otherwise should have done. Professor Arnold was well able to put such matters as he was dealing with that night clearly before them, and he was sure that they would be very glad indeed to have had this Meeting after they had heard Professor Arnold's remarks and the discussion which was to take place upon the Report.

Professor Arnold then read his Report on "The Chemical and Mechanical Relations of Iron, Cobalt, and Carbon."

Discussion in Glasgow.

The CHAIRMAN said that before the discussion was entered upon he thought they would allow him to thank Professor Arnold for coming from Sheffield to speak to them that night, and for the very lucid and clear exposition he had made, not only as to the subject of the Report, but also what he was sure had been interesting to every one of them, namely, the collateral question of the influence of the other elements on the qualities of steel, and though, so far as he could gather, it did not seem to have been proved that there was any very immediate value in cobalt-iron alloys for them as engineers, still they would hope that this investigation, like so many others, would ultimately prove of great advantage to practical men.

Mr. JOSEPH JEFFERSON (Coatbridge) said he wished to express his appreciation of the Report which had been put before them by Professor Arnold. When they came there and listened for an hour or so to a Paper of this kind, he was sure that they did not always fully appreciate the labour and time involved in the preparation of it. Personally, he had had the pleasure of working along with Professor Arnold for a number of years, so he thought he had some idea of the work and time involved in preparing such a Report. The first Paper of special interest to the steel trade by Professor Arnold was published over a quarter of a century ago—perhaps Professor Arnold would correct him if he were wrong—when he gave to the public, or rather to the steel trade, who made use of it, the discovery in connexion with the manufacture of steel, namely, that crucible steel could be "dead melted" by the addition of a small percentage of aluminium, without the usual "killing fire," and so making an economy in fuel.

Professor Arnold had been giving them the results of his researches ever since, and the number of elements experimented upon had grown to such a remarkable extent that the Paper on Aluminium was now almost lost sight of, although the principle put forward so long ago was made use of, more or less in practically all

the steel shops and steel foundries of to-day. It also allowed such pure steels or alloys, as the cobalt series presented now, to be made, as they were practically free from silicon and manganese.

Personally, he had not had the opportunity of experimenting with cobalt. From its similarity in chemical properties to nickel, he would have expected its influence on steel to be much the same as nickel, and now when supplies were so uncertain, it was possible that if he had run out of nickel in the works for the manufacture of special castings, he would have been tempted to try cobalt, but from the results set forward in this Report he now knew it would have been useless.

Dr. Cecil H. Desch (University of Glasgow) said that from the point of view of the metallurgical chemist, Professor Arnold had contributed a number of very important facts, as he had done in his previous Reports on this subject of carbides. The most striking chemical fact in the Report was the extraordinary difference between two such closely related elements as cobalt and nickel. In their salts they were extremely similar, and yet in their carbides and the alloys into which those carbides entered, there were such remarkable differences as those which had been found by Professor Arnold, and which, he thought, no chemist would have predicted.

One difficulty which met the speaker when he was reading the Report, before Professor Arnold had cleared it up by his remarks that evening, was with reference to the condition in which the cobalt was present in these specimens. When the Tables were examined, the cobalt carbide appeared to be in a state of solid solution rather than in the form of separate compounds, and he understood that Professor Arnold considered that to be the case. It was somewhat remarkable that the relations between cobalt and nickel on the one hand, and carbon on the other, should be so much affected by the presence of a large excess of iron. The authors quoted (page 249) from G. Boecker's work on mixtures of cobalt and carbon in the absence of iron, showing that cobalt carbide was completely unstable. In the presence of iron its stability was increased. Since the Report was written, a Paper by Ruff had

(Dr. Cecil H. Desch.)

appeared, dealing with the relations between cobalt and carbon in the absence of iron, and Ruff's work confirmed that of Boecker and also seemed to show that at very high temperatures cobalt carbide, like other endothermic compounds, had a range of stability and became unstable as the temperature decreased.

He felt in perfect agreement with Professor Arnold in his remarks about hardness. He did not say that he agreed at all times with Professor Arnold's views on hardness, but with what he had said that evening on the general question he was in perfect agreement. Hypotheses devised to explain the hardness of one or two varieties of steel could not be regarded as satisfactory. He believed that until we knew what was the physical meaning of hardness, theories of hardness would not make much progress. Until we knew what was the actual molecular condition which produced increased hardness in a solid crystalline substance, it was almost useless to put forward special theories of the hardness of steel. The problem, why diamond was the hardest substance, seemed to have very little connexion with the hardness of tool-steel, but he agreed with Professor Arnold that until both questions were answered, the second could not be satisfactorily solved. He felt that the Report was not only of value to engineers, but also of great interest from the chemical point of view.

Mr. A. McCance (Glasgow) said it was unnecessary for him to emphasize the value of Professor Arnold's work on the chemical relations of carbon with iron and its alloying elements. It was more than ever desirable at the present time to extend and multiply experiments on this subject, because that was the only way in which knowledge would ever be gained.

Some years ago he had had the opportunity of examining a series of cobalt steels in which the cobalt was present up to about 9·0 per cent., and the carbon up to 1·5 per cent., and the conclusion he came to as a result of this examination was that, so far as structural steel was concerned, the addition of cobalt had so little effect that it was commercially useless as an alloying element. It seemed to raise the tensile strength, when 9·0 per cent. was present,

about 6 to 8 tons almost independent of the carbon content, and it had no effect on the microstructure. Since cobalt, then, had such a small effect on steel, he thought that one ought to be very sure of one's data indeed before classing it as a carbide-forming element along with chromium, tungsten, molybdenum and vanadium, which were all elements with a very decided effect on the strength and a noticeable influence on the microstructure. The formulæ proposed by the authors had this disadvantage, that until he knew definitely the percentage of graphite present in his separated carbides, he (Mr. McCance) did not think it could be definitely stated that cobalt carbide had been formed.

On separating carbides by electrolysis in dilute acid solutions, there was always some decomposition of iron carbide with the formation of graphite, and that was why, instead of getting the theoretical 6·66 per cent. of carbon in the carbides, one got a much higher result. In the present case of cobalt steels the percentage of carbon in the separated carbides varied from 7·0 to 7·5 per cent., but the actual percentage of *combined* carbon could not be stated. If this were found to be always about 6·66 per cent., it would prove Professor Arnold's contention that Co_3C was formed and dissolved in Fe_3C in varying proportions giving a series of mixed carbides. He (Mr. McCance) believed, however, that the existence of cobalt carbide had not been proved, and he even went so far as to say that the chances of it existing in steels at all were very small. Cobalt was soluble in iron. Could it not also be soluble in iron carbide? Taking the general effect of cobalt into account, this seemed a very probable view: that a proportion of the cobalt added to steel dissolved as such in the cementite, while the remainder dissolved in the ferrite. On this view the percentage of combined carbon in the separated carbides should fall as the amount of cobalt increased, and it was on this account that it was desirable to know the proportion of graphite in the carbide which Professor Arnold had separated.

There was one point regarding the details of the analysis made by Professor Arnold that he might touch on. In the Report it was stated that in the analysis of the carbides the carbon was estimated

(Mr. A. McCance.)

by direct combustion, and then the iron and cobalt were determined separately, but he (Mr. McCance) noticed that all the analyses totalled up to 100·00 per cent. That was a very remarkable accuracy, and he would like to know if he had read the statement correctly, and if so, what had become of the small quantities of impurities, such as manganese, etc.? Of course, this was merely a matter of detail, but it was desirable at all times to have the fullest information possible, and Professor Arnold's work on the subject of carbides in steel was the one and only source of information which metallurgists possessed on the chemical side of the question, and it was of the very highest importance.

Mr. W. M. URIE said he had listened with great interest to the Report, but unfortunately he had not any particulars about tungsten steel with him, although he had conducted a great many tests on it. The steel they relied upon most, as Professor Arnold had remarked, was Mushet steel, which gave excellent results. The special quality was quite good, but for reliability Mushet titanic was most satisfactory.

Professor ARNOLD, in replying to the discussion, said he was very much obliged to the gentlemen who had taken part in the discussion for their kind remarks. He was glad to see his old friend Mr. Jefferson there, and his presence showed that although he had left academic life, and his interest now was very largely from a manufacturing point of view, he yet kept up an interest in these things from a scientific point of view.

With regard to the question of hardness, one or two remarks made by Dr. Desch appealed to him very much. If we took iron containing 0·89 per cent. of carbon and heated it up to 730° C. and quenched it, it changed from a compound structure which was really an alternating lamina of iron and of carbide of iron Fe_3C, and under those conditions we got a perfectly structureless yellow substance, Hardenite (which his friend Sorby had discovered), which held the 13 per cent. carbide of iron in solid solution. He took it that the hardness was due to an inherent property of that

particular solid solution. That was a fact found out a long time ago—away back in the time of Homer. No discussion on the hardening of steel could be complete unless it dealt with the facts established in these carbide researches, that there were three true steels, namely, iron steel, vanadium steel, and tungsten steel. If one took true vanadium steel, heated it to a red heat, and quenched it, it was quite soft, although containing 1 per cent. of carbon; if it were now heated to a bright yellow and quenched, it was still quite soft; heated to a yellowish white and quenched, it was yet soft. When quenched, however, from a white heat, it was tremendously hard, but so brittle as to be of no practical use; the steel in that particular form was only a metallurgical curiosity. On the other hand, if one took tungsten steel, with $11\frac{1}{2}$ or 12 per cent. of tungsten and 0·7 of carbon, and heated it, say, to 850° C. and quenched it, it was quite soft; go on to 1,000° C., it was still relatively soft; go on to 1,100° C., it was hard; go on to 1,200° C., it would strip a file. This fact, as he had said, was found out long ago by practical engineers, before scientific men explained it. In fact, in the late "Eighties" a label was issued giving instructions describing exactly how to carry out this operation with high tungsten steel, showing that by going higher and higher, one got it harder and harder, and that with high high-speed steel we were face to face with an utterly different substance from the plain carbon steel. He was very glad to hear Dr. Desch's views. There was one point on which he would like to comment. The cobalt *per se* was not in solid solution, but the carbide was.

Dr. Desch said he understood that was so.

Professor Arnold, continuing, said that frequently in these researches they found carbides in solid solution. He was anxious to make that point quite clear. He was very much obliged to Mr. McCance for his kindly criticism. He was not sure whether he caught what Mr. McCance said aright. Mr. McCance was speaking, he thought, about nickel. He did not think that ordinary commercial steels had beyond a trace of nickel carbide, at any rate up to 7 per cent. nickel.

Mr. McCance mentioned that he was referring to cobalt.

Professor Arnold, continuing, said there was graphite in only the highest member of the series, namely, that with about 21 per cent. of cobalt. The carbonaceous residue was a brown flocculent hydrate. Taking the surplus carbon over theory, and calculating that to cobalt carbide, we practically raised the amount of Co_3C in the iron carbide from 6 to 12 per cent., and assuming the whole to be solid solution, it brought the carbide column out correct, and it also brought the microscopical data into line. With reference to the perfectly legitimate point on analysis brought forward by Mr. McCance, he might explain that the Mn_3C and SiO_2 in the residues were very small, and the analyses were the mean of triplicate estimations stated to the nearest second place of decimals.

He was interested in the remarks about the Mushet titanic steel made by his friend Mr. Urie. He might say that the great feature of Mushet titanic steel was that it did not contain titanium. In conclusion, he was very much obliged to the gentlemen who had been good enough to take part in the discussion, and he thanked all those present for the kind attention they had given to what was, he was afraid, a somewhat dry subject.

The Chairman said he thought their first experiment in holding a Meeting of the Institution of Mechanical Engineers in Glasgow had been quite a success, and he was sure they were interested in having present with them that night Mr. Worthington, the Secretary of the Institution, to whom they would give a hearty reception.

Mr. Edgar Worthington (Secretary of the Institution of Mechanical Engineers) said it would be his duty to report to the Council of the Institution the result of this Meeting in Glasgow. Quite a third of those present were visitors from other Societies, and he felt sure that the Council would wish a hearty welcome to be extended to them. The system of holding Meetings in the

Provinces at the request of members in the neighbourhood had been practised for some months; such Meetings had been held in Manchester and Birmingham, and the members of kindred Societies had been invited. The presence of so many members would be an encouragement for holding further Meetings when the subjects dealt with were of special interest to Glasgow members. When an author like Professor Arnold could present his Report a second time, there was no reason why the discussion at a local centre should not be as interesting and full as it was in London.

In connexion with what had been said about hardness, members would bear in mind that a Research Committee of the Institution was investigating this subject, more particularly to try to suggest a unit of hardness. When this Committee reported, a very interesting subject would be offered for discussion. As was known to most of them, the proposal to hold Summer Meetings of the Institution in leading centres of engineering throughout the Kingdom originated in 1856, the first having been held at Glasgow, in September of that year, under the Presidency of Mr. Joseph Whitworth (afterwards Sir Joseph Whitworth, Bart.).

The Chairman remarked that this closed their proceedings, and he only hoped that on the next occasion on which they had a Meeting of the Institution of Mechanical Engineers in Glasgow, they would meet under more favourable circumstances than they did that night. Perhaps Professor Arnold might be a little disappointed with the size of the audience, but so far as he was concerned he was surprised that it was so large. At the present time they in the Clyde district were all so exceedingly busy with war work, and most of them had very little time to spare; still, it was good for them to meet together on such an occasion as this and hear such a well-known authority as Professor Arnold discussing the subject which he had made so peculiarly his own.

The Institution of Mechanical Engineers.

PROCEEDINGS.

APRIL 1915.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 16th April 1915, at Eight o'clock p.m.; Dr. W. CAWTHORNE UNWIN, F.R.S., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the following Transference had been made by the Council:—

Associate Member to Member.

DALZELL, HAROLD EDWARD, ... Arequipa, Peru.

The PRESIDENT then delivered his Inaugural Address.

The Meeting terminated shortly after Nine o'clock. The attendance was 88 Members and 21 Visitors.

ADDRESS BY THE PRESIDENT,

W. CAWTHORNE UNWIN, LL.D., F.R.S.

I first desire to express my sense of the honour you have done me in electing me your President. So far as I have felt reluctance in assenting to the wish of my predecessor that I should be nominated to that office, it was mainly that my age is a disqualification. I lack something of the energy and élan of an earlier time. But I did not like to shrink from an effort to be of service to my profession, and to an Institution of which I have been a Member for thirty-seven years, and to which I owe so much. I trust, with the assistance of your Council and of your energetic and devoted Secretary, and with your good will, that the Institution will suffer no detriment during my term of office.

The direction of the affairs of the Institution, in these anxious times, is, I feel, a task for all that a man has of fortitude and delicacy. I follow a distinguished President who grudged no time or labour in the service of the Institution.

I was diverted from the active practice of constructive engineering, and my activities have been largely confined to the study, the class-room, and the laboratory. But it has been a matter of gratitude and surprise to me that what little I have been able to do, has been so generously appreciated by other engineers. Nothing is more significant in the last half century than the growing importance of engineering. The engineer is more and more looked up to for the solution of industrial, civic, and

national problems. The War has not left us as we were before. In standing shoulder to shoulder in a common cause, in consenting to some abbreviation of liberty, we are losing a little of our extreme belief in individualism and our suspicion of State action, and that is likely to increase the sphere of work and the demands on the expert knowledge of the engineer.

Perhaps in war time there might well be a moratorium of Presidential Addresses. But it has been thought better that the tradition of the Institution should not be broken, though at a time when ordinary engineering topics are overshadowed, its fulfilment is difficult.

The Institution.—The work of the Institution in the past session is fully described in the Report of the Council. The Summer Meeting in Paris, when visits were made to Lille and other manufacturing towns in France, now devastated, was pleasant and instructive. The rate of increase of membership, as would be expected in present circumstances, has diminished a little, and it may be that in the coming year there will be some actual reduction. The Institution owes to Mr. Charles Hawksley an exceedingly generous gift, forming the capital of the Thomas Hawksley Fund, to perpetuate the memory of his father, a Past-President of this Institution and also of the Institution of Civil Engineers. The income of the Fund is applied to founding a Lecture to be delivered annually both at the Institution and at some local centres of engineering. The Lecture prepared this year by Mr. W. B. Bryan was, owing to his lamented death, delivered by his son, Mr. B. W. Bryan, here, and in Manchester and Birmingham. The Thomas Hawksley Fund also permits the annual award of a Gold Medal for the best Paper of the Session. The awards for 1913 and 1914 have recently been made.

By a still more generous gift, Mr. Charles Hawksley has provided the cost of a Laboratory for Hydraulic Research at the City and Guilds College, which will be the most perfectly equipped of any in this country.

The Institution as a corporate body of men of similar avocations

is a source of strength to all its members. It gives publicity to the work of engineers, which is essential in creating the estimation in which they are held by people outside the profession. It is able to secure facilities and gifts, and it elicits and records information of great value which would otherwise remain private property. One has heard of persons who think that because they cannot attend the Meetings in London, and have no time to study the Proceedings, they can get no benefit from the Institution. The case is rather an extreme one. Bacon said that every man is a debtor to his profession, and it follows that he has a duty to support whatever benefits it. Most of us subscribe to objects from which we expect no direct recompense, and few engineers could say that they receive no indirect benefit from the work done here. Knowledge diffuses itself in various channels, and improvements in industrial methods bring advantage to many who do not know where they originate.

Recruiting.—The Institution, at the invitation of the Admiralty, took an active part, in association with the Institutions of Civil and Electrical Engineers, in recruiting an Engineer Unit for the new Royal Naval Division. A unit of 500 men was completed last September, and a number of the men received Commissions. Part of the Division is already on active service. Later, 21 candidates nominated by the Institution received temporary Commissions from the War Office in the Royal Garrison Artillery. Further demands are being made for the exercise of the influence of the Institution, and it should be acknowledged that a great deal of work in connexion with recruiting has fallen on the Secretary. It is believed that not less than 400 members of the Institution are serving in one capacity or another in H.M. Naval or Military Services. I think the Institution has fully done its part in assisting the country in this time of emergency.

Local Meetings.—The Council has endeavoured to meet the wishes of country members, and to make the Institution more useful to them by holding Meetings in local centres, for repeating a

Lecture or Paper previously given in London, and these have been very fairly successful. It is hoped that country members will realize that the Council is very willing to help them in such ways as are practicable.

The Examinations.—Membership is accepted as, to some extent, a certificate of competence, and its value is due to the fact that entrance to its ranks is guarded. A candidate must be proposed, must state his qualifications, and must run the gauntlet of strict scrutiny by the Council, and finally by the members at large. Mistakes may be made, for it is human to err at times, but very great care is taken.

The appraisement of the qualifications of candidates is not easy, and is specially difficult in the case of younger candidates who have no long record of work. Hence the Institution, following the example of the Civil Engineers, the Architects, the Surveyors, and other Institutions, has instituted an examination for candidates under thirty years of age. No doubt an examination test is not infallible, but it more often lets through the doubtful than it excludes the qualified. Dr. Welldon, when pointing out some evils of crude methods of public competitive examination, said that the attaining of a standard rather than supremacy over competitors was the best means of selection. Now, our examination is of that type. Also the diplomas of various Universities and Technical Schools, granted on conditions which are trustworthy, are accepted in lieu of our own examination.

The examination does secure that young engineers are stimulated to study seriously principles involved in engineering practice and mathematical tools useful to the engineer. Though the examination looks like an obstacle, I do not think that in after life any one who has passed it will complain that he was driven to study, at a time when the mind was receptive and tenacious, "wax to receive and marble to retain."

Although this year the examinations have been a little interfered with, some candidates having gone to the Front, I think it is satisfactory that since the examination was established

23 Graduates and 39 Associate Members have passed the examination, and 43 Graduates and 26 Associate Members have been admitted on the ground that they had passed an equivalent exempting examination elsewhere.

Research.—This Institution has distinguished itself very honourably by fostering research in subjects important to engineers. Some of us who move in professorial circles get, perhaps, a little tired of the insistence on the importance of research for students. Research for the solution of new problems is of great importance, but it is not a task for young and immature students. Many so-called researches, in which well-understood methods are applied to materials or subjects not themselves important, hardly deserve the name. They amount to little more than class exercises. Most scientific societies receive Papers in which a much over-elaborated description is given of known proceedings and precautions, in which the new results are of limited value without establishing any general law. But the value of real research, based on a clear formulation of a definite unsolved problem, cannot be overestimated.

Unfortunately, in engineering, the solution of unsolved but important problems is generally both difficult and expensive. Much, no doubt, is done by manufacturers who have a financial interest in the work. But their researches are, in general, not fully published. It is of great interest to the public at large and to other engineers that a scientific Institution like this feels it part of its duty to advance knowledge by research, and is able to devote a fraction of its income for such researches as are beyond the means of private persons. In most cases, a Research Committee of this Institution begins by an investigation of what has been done before, and the summary of previous investigations which the Institution publishes is not only a safeguard against mere repetition of experiment, but is valuable in itself. Professor Martens, the director of the great State laboratory at Grosslichterfelde, has said that in four cases out of five when a manufacturer brings him a problem, it is found that it has already been solved somewhere by somebody.

The War and Engineering.—We meet in circumstances not foreseen a year ago. A war of unprecedented magnitude, extending over a vast area, has broken on us with the suddenness and fury of a tropical storm. We are already proud of the courage and military skill of our Army, the magnificent work of the Navy, the resource of the Government in meeting extraordinary emergencies, and the patriotism of our people. As engineers, we know that our dockyards, arsenals, and armament firms are great schools of technology where the utmost resources of science and experience have been utilized. Victory, if we reach it, as we confidently trust we shall, will largely be the result of the general progress in mechanical engineering and in the capacity of our factories and workshops, due to the concurrent exertions of all engineers, civilian and military. As Mr. Lloyd George has said, "this is an engineer's war, for equipment was even more needed than men." An immense work is being done by private firms in supplying the wants of ourselves and our Allies. We have to overcome the material resources of an enemy who had made long, deliberate and, as he believed, adequate preparation.

In this war the question of transport for troops, for munitions, and for food has assumed an importance never experienced before. It is only by the use of every mechanical appliance that a war on the scale of the present one is possible. Conveyance of food, munitions, and troops beyond railheads to the nearest possible point to the firing line, depends almost exclusively on motor traction. The vehicles comprise columns of motor-lorries, box-cars, motor-ambulances, motor-omnibuses for troops, motor-cars for officers, steam-tractors for guns and travelling kitchens. It has been necessary to provide large stores of spares and well-furnished repair shops.

I think we may regard the conveyance of the Expeditionary Force as a triumph of organization. A Committee of Railway Managers, formed before the War, had studied the necessary arrangements. Three hundred and fifty trains were at work, and they arrived at Southampton from all parts of the country, between dusk and dawn, at twelve-minute intervals, during ten days. The

troops and their heavy equipment were detrained and embarked without a hitch, and, guarded by the Navy, were transported to Boulogne without molestation.

As engineers, we may recall with pride the words of Mr. Churchill in regard to the ships at the Falkland Islands Battle and the Cruiser Raid. He pointed out that "all of a sudden the greatest trial was demanded of the engines, and they excelled all previous peace time efforts. Can you conceive," he said, "a more remarkable proof of the excellence of British machinery, of the glorious industry of the engine-room branch, or of the admirable system of repairs and refits by which the Grand Fleet is maintained without exhaustion?" In this connexion I should like to refer to the reform effected by Lord Fisher, conferring military rank upon the old entry engineers of the Royal Navy. Hitherto, in spite of their invaluable service and the risks they ran, they were rated as civilians. Lord Fisher said that "the unapproached efficiency of the engineers in the Navy merited this tardy recognition of their all-important part in the splendid fighting condition of our whole Fleet."

If in this War the work of the mechanical engineer has assumed a new importance, if success depends on an enormous supply of munitions, if, as Mr. Lloyd George said, "the turning out of munitions of war not merely means success, but means the saving of lives," then a great responsibility is placed on the shoulders of engineers. They are called on for the utmost exertions and perhaps for more sacrifices than others, except those at the Front. It is clear, though it has been slowly realized, that the magnitude of the War is such that all previous calculations of the requirements in war have been too small, especially as we have to supply our Allies' needs as well as our own. The conditions are new and perplexing, and our enemy has foreseen the magnitude of the requirements and organized his material resources at leisure. But I doubt not that British grit and loyalty will not be called on in vain, and that engineers, both employers and workmen, will do all that is humanly possible to meet the emergency.

Foreign Competition.—Nevertheless a retrospect of our methods and activities is not entirely favourable. *Fas est et ab hoste doceri*,

and it is no condonation of the military crime of Germany to recognize that the enormously rapid industrial advance in that country has serious lessons for us. Before the War many of us had an immense respect for German science and learning. We have not lost that because we now appreciate the inordinate vanity, the preposterous political ambitions deliberately fostered among Germans, and the insolence of the army. Certainly, since 1870, the mind of the ruling and influential classes seems to have lost balance and reasonableness. So deep is the obsession of aggressive so-called Kultur, that even among Germans living abroad in freer conditions, and with sources of information not open to those at home, few seem yet to realize the evil of Prussian militarism. But it is striking that a German Canadian, in the House of Commons at Ottawa, said that "German art, science and music is one thing, but Prussian militarism another, and the reason so many persons of German origin left their Fatherland was to escape military domination. To-day," he said, "they are as eager as the British for the obliteration of the curse which has been weighing on Europe." Consider these facts. In sixteen years the aggregate income of Prussia has nearly doubled. While our Mercantile Marine increased from 9 to 10 million tons, that of Germany increased from 1 to $2\frac{1}{2}$ million tons. In 1870 Germany had 7 shipyards employing 3,000 hands; in 1900 she had 39 shipyards employing 40,000 hands. Although Germany has on the whole poorer qualities of iron ore and coal, her production of pig-iron increased from 11 to 19 million tons annually, while ours increased only from 9 to 11 million tons. To-day her production of steel is nearly twice as great as ours.

I am not among those who think that to import materials or products is necessarily to diminish wealth or the demand for labour in this country. We quite rightly prefer home-made goods. But it is natural and desirable that each country should take full advantage of its natural resources, its position, its climate, and its enterprise. Broadly, imports are paid for by exports, and if we ceased to import we should have no foreign markets. Whether the sale here of surplus products at a low price, made possible by

Protection, is an advantage to us is open to argument. But Lord Aberconway has pointed out that "to take one instance, which represents others, the tinplate and sheet mills in South Wales are to a large extent kept going, on a profitable basis, by the fact that they consume great quantities of German steel billets, at a price much lower than they could buy material made in South Wales."

On the other hand it is not satisfactory or safe that we import so many things from Germany, for the production of which she possesses no special advantages, and that in some cases important industries have become absolutely dependent on foreign supplies of manufactured products. It is one thing to exchange goods with another country, it is another thing if from sluggishness, or want of enterprise, we allow another country to obtain a monopoly of things we cannot do without.

Various artificial conditions have fostered German trade, some of which might, and others could not, be imitated with advantage. The German Government is poorer than ours, but it has much more clearly recognized the interdependence of science and industry, and the duty of the State to assist industry in matters beyond private initiative. It has spent very much more in providing the highest type of technical instruction and State Research Laboratories. The railways and canals being under State control, differential rates can be adopted to help traders. The banks, advised by a staff of scientific, legal, and commercial experts, have been ready to promote the trial of inventions, and to subsidize promising but necessarily speculative industrial undertakings on a scale unknown in this country. Amongst other influences which have adversely affected our manufacturers may be reckoned some perversities of the Patent Law. Hence it has come about that, since the War began, we find ourselves in want of important products we can no longer obtain, and we realize that Germany fights not only with her army, but with her science and industry.

The most striking examples of the plight to which we have been reduced are found in the chemical industries, which, however, involve a good deal of mechanical engineering. Aniline mauve was discovered in this country in 1856, but the Germans,

and to a certain extent the Swiss, have practically captured the whole colour industry. Professor Meldola stated that, in 1886, nine-tenths of the dyeing colours used in this country came from Germany. Yet these are essential to textile industries having an annual output of £200,000,000, employing 1,500,000 workers. The production of synthetic indigo in Germany has largely destroyed the cultivation of natural indigo in India. The value of imported indigo from India in 1895 was about £3,500,000. At the present time it is about £70,000. Baeyer discovered synthetic indigo in 1880, but nearly twenty years were employed in research and nearly a million pounds was spent before commercial synthetic indigo was placed on the market. That is immensely creditable to German faith in science. Before the War the world's demand for electrical porcelain was practically met by Germany alone. There are many other similar cases. In these industries Germany had no natural advantages, but only a greater scientific intelligence and greater confidence of financiers in supporting scientific advisers.

Lord Moulton has said that "after the War, if we do not effect a change, the textile industries would step into a slavery to the Germans as great as that in which they hoped to put us in a political and military sense."

To take another instance of more interest to engineers. Germany has acquired a practical monopoly of the treatment of the complex ores of the baser metals. The whole of the ores of zinc, lead, and silver from the mines of Australia, the richest in the world, are under contract sent to Germany for reduction. The Australian Attorney-General stated that "German influence exercised a monopoly over the world's base metal industry, so complete that it excluded effective competition."

Happily, in the iron and steel industries we are in a better relative position. Metallurgists here and in Germany, Belgium, and the United States have learned much from each other, and we have no reason for dissatisfaction with our part in the progress made. We had a long lead, and the discoveries of Bessemer, Mushet, William Siemens, Thomas and Gilchrist, and others kept us in the front rank. We have been outpaced in volume of

production, but in the higher qualities of steel and steel alloys, both in investigation and the quality of our product, we still hold a lead. The large demand for warships, guns, and projectiles has no doubt been a favourable factor. The establishment of laboratories directed by competent experts in steel works and the works of large consumers like the railway companies has tended to the improvement and standardization of quality.

Nevertheless we do not maintain superiority in all departments. In the heavy steel and machinery trades we have a dominant position, but for lighter machines Germany, the United States, and Scandinavia have secured a large market. In the case of light and medium steel castings—those required for motor-cars, for instance—this country has become almost dependent on Germany and Switzerland. The use of steel castings has very greatly increased, and they add in an important way to engineering resources. So far as a reason can be found for the better and more uniform quality of Continental steel castings, it lies in the adoption abroad of the electrical furnace and great attention to heat treatment. Many of the steel castings come from Switzerland, where the cost of raw materials must be greater than in this country, and the cost of carriage must balance the lower labour cost.

There is another point. After the War, when happier conditions return, our manufacturers must be willing to give designs, specifications and estimates in metric measures for countries where the metric system is adopted. The use of the metric system is legalized, but its compulsory adoption is not likely to be enacted, at any rate for a considerable time, if indeed it is desirable, about which a good many of us have doubts. Meanwhile, in many branches the use of a double system of metric and English measures involves little difficulty. In fine machinery no doubt it is troublesome, but that at present must be faced.

Technical Education.—Samuel Butler said that life is the art of drawing sufficient conclusions from insufficient premises. It is certainly true of the engineer, not engaged in mere repetition work, that he has constantly to arrive at conclusions and to act on

insufficient data. Probably no difficult engineering problem has ever in the strict sense been completely solved. The engineer has to make assumptions, to use approximate theories, to decide between material and negligible considerations, and to allow for unknown contingencies. Now, scientific training, if sufficiently advanced, does enable us to solve most problems which are clearly stated and data given, but its usefulness does not end there. The trained engineer with incomplete data reasons correctly, estimates probabilities, and knows the limit of the trustworthiness of his conclusions. He does not snatch at a pocket-book rule and ignore the assumptions on which it is founded.

Among the various causes which have contributed to German industrial development, a thorough and widely diffused technical education must be given an important place. The branches of industry in which Germany has acquired a dominant position are those in which advanced applications of science are most necessary.

I notice that, in a Report prepared by the Engineers' Club of Manchester, it is stated that the British engineering industry would derive incalculable benefit from an increase in the number of highly trained experts, and would then be able to dispense with the services of Germans, who have had to be employed for lack of qualified Englishmen.

In the highest branches of scientific discovery this country has held a very distinguished place. That has been largely due to men who pursued science without regard to any practical end, or even with a certain disrespect for the fruitful applications of science. The value of this pursuit of pure science is of course not to be underrated. Manufacturers, on the other hand, who are interested only in applications of science, have been a little contemptuous of scientific men who seemed indifferent to business. All that is no doubt gradually changing. The means of obtaining technical knowledge, and the desire to take advantage of it, have increased. But even yet we have no institutions quite equivalent in buildings, equipment, and staff to the great Technical High Schools on the Continent. In Germany and Austria, excluding chemists, there are four or five times as many students in Technical High Schools

as in Colleges of corresponding rank in Great Britain. America, Belgium, and Switzerland in this respect have closely followed Germany.

If I speak with admiration of the intellectual efficiency of German education, it is not that I like the Germans or that I do not see some serious evils in their system of education. Our English system is in many ways intellectually deficient, but it encourages initiative, individualism, and a high sense of honour. In Germany all education is State controlled, and made to subserve State interests. In 1898, the Kaiser said that "he had firmly resolved that the theatre, the university, and the school should be instruments of the monarch." In accordance with this the schools and universities are the seat of political propaganda, and cultivate the spirit of aggressive and arrogant patriotism which has been revealed in the War. There has been systematic teaching of what Dr. Sanday calls an Anti-British legend. As never before, professors, in Germany, have influenced the course of events and taken public part in defending an aggressive war.

But now, putting aside political and moral considerations, it is the thorough and advanced character of the education in the Technical High Schools and the researches of their professors, to which indeed many of us are greatly indebted, which have so directly promoted German industry. It is sometimes said that the Germans only pick up other people's discoveries and apply them. I think that is untrue, or at least greatly exaggerated. As Dr. Ormandy has well said, "those who adapt scientific discoveries to industrial use are as entitled to honour and reward as those who made the original discovery." But there is another aspect of education in Germany which has a lesson for us—the German secondary school is far more efficient than ours. Lord Haldane said that "in this country we have never understood the significance of the secondary school. In Germany the whole educational fabric rested on it." Secondary education in Germany is State supported and definitely graded. The Gymnasium, the Real-Gymnasium, and the Real-Schule are organized to meet the wants of boys intended for different careers. Further, the

universities, the professions, and higher government appointments (including those on railways) are practically closed to all who do not pass a severe State maturity examination after nine years' schooling. The precise arrangements differ in various States, but in each there is an organized system and great pressure on boys to reach a high standard. All those who pass the maturity examination are excused one year's military service. The importance of that for us is that a great obstacle to really efficient technical instruction in this country is the inadequate preparation for it in the schools. Practically a year of the three years' college course must be given to work which could well be and ought to be acquired in school by lads of 17 or 18. Perhaps the excessive attention to athletics has something to do with our intellectual shortcomings.

I readily admit, what is asserted on good authority, that the English system of classical education is the best for Civil Service and administrative posts. I feel sure it is not a good preparation for an engineer. The Dean of Manchester, Dr. Welldon, has said that "it seemed to him that to demand a knowledge of two dead languages from all boys who were going to a university was to cramp and fetter their intellectual development." *A fortiori* it is unsuitable for lads going into practical careers. It is a part cause of our discreditable ignorance of continental languages.

I have spoken of the value of an advanced type of technical education for engineers who aspire to positions of responsibility, but I do not overlook or underrate the necessity of practical experience. Both are necessary, but one should not be cut down at the expense of the other. Sir Frederick Donaldson put the case for practical training in an admirable Address two years ago. There are many branches of engineering, and as to the relative importance of technical instruction, workshop, field and office training, in different cases, there may be differences of opinion. Further, I am far from advocating the Germanization of English education. Only it seems to me that some of our educational tools, like some of our workshop tools, are mediæval and out of date, and that some of our faults need a remedy. If, as I suppose, the cost of the War must be paid out of the profits of industry, it is of importance that our

efficiency should be increased. Sir George Reid has said that "captures of German trade in time of war will only be retained in time of peace by the capture also of the scientific methods of the Germans."

Testing Materials.—Half a century ago, most materials of construction were selected and bought on the reputation of the manufacturer. Experience roughly indicated the sources from which the most reliable supplies could be obtained. Now hardly any material in large use is accepted without special testing in the interest of the purchaser. Such testing is primarily intended to distinguish suitable and unsuitable material and to protect the user from carelessness or fraud. But it has also acted as a stimulus to manufacturers to standardize and improve their products. Once it is known how good a quality can be produced, all manufacturers strive to reach it, and the average quality is raised. The rapid development of cement and of the higher qualities of steel has depended on the determination of their superiority by accurate tests in the properties required for special services.

With the introduction of mild steel, the quality of which ranges between wide limits, the need of systematic testing became urgent. Now there are testing laboratories in the works of most railway companies and in steel works. Also the practice of testing has been adopted in the case of many other materials. With the extension of testing has come the need of standardizing tests themselves, a work now largely accomplished by the International Association and the British Standards Committee. But with the increasing stringency of specifications, perhaps more attention should be given to the calibration of the instruments used in testing. In physical investigations great attention is given to the determination of the errors of instruments and methods, and perhaps in material testing this has received too little attention. I do not suppose there are important errors in the indications of large testing machines, though a comparison of results in different laboratories would be interesting. Errors in subsidiary apparatus are probably more frequent. It is possible with a standard bar and

a good extensometer, used by the same practised observer, to measure the agreement or disagreement of different testing machines. I have found also the use of copper cylinders subjected to crushing to be a very convenient means of checking load indications of machines.

On the Continent and in the United States there are public laboratories, supported by the State, where anyone can have tests made, at moderate fixed rates, by a trained scientific staff and with great accuracy. Such institutions assist industry if, on the one hand, they meet industrial requirements, and, on the other, are unbiased by private interests. They have the advantage over private laboratories that they are under the direction of experts of exceptional experience and reputation, and are able to pursue investigation, continued often for long periods, beyond immediate requirements into fruitful by-paths. The view taken in Germany is that the work accomplished is partly of advantage to the manufacturer who calls for assistance, and so far should be paid for by him, and partly is of advantage to the nation in advancing science, which is the justification for a State subsidy. Hence it is incumbent on the public institution to publish results as freely as is possible without injuring private interests.

At Grosslichterfelde the annual income from fees for testing amounts to £20,000, and the annual State subsidy is £12,000. On the staff there are 230 persons, of whom 75 have had University training and 38 Technical High School training. Since 1880 the work accomplished has steadily and regularly increased.

The Bureau of Standards at Washington is on a still larger scale, and does very similar work. It receives an annual subsidy from the Federal Government of £100,000. The equipment is extraordinarily complete. For instance, it has a 600-ton testing machine at Washington, and a 1,000-ton testing machine at Pittsburg, both of the highest sensitiveness and accuracy. Such machines do not exist in this country. Happily, we have now a similar institution in the National Physical Laboratory at Teddington. Its functions are somewhat restricted by the characteristic English jealousy of State action, which I think is

diminishing. It would be difficult to overestimate the service it has done in the solution of various mechanical, electrical and physical problems which were unlikely to be attacked by private persons. Some of the researches started by this Institution have been carried out there, and valuable Papers contributed to our Proceedings. The superiority of English aeroplanes has been demonstrated in the War, and their services for scouting and for directing artillery fire have been invaluable. When the Government required difficult experimental investigations to be carried out on aeroplanes, it found at Teddington a staff and an organization already in existence and suited to the purpose.

It is a condition of commercial testing that the results should be available in a short time and at small expense. Hence ordinary tests are of a somewhat arbitrary character, and do not completely imitate the conditions of actual service. We test specimens of steel to destruction and measure ductility by plastic deformation, though in use the stresses do not exceed the elastic limit and the deformation is elastic. We test cement in tension and use it in compression. There is need for constant criticism of methods of testing and for the invention of new tests, such as tests for hardness and brittleness, although new tests must be cautiously introduced.

One small change could be easily made, and in some cases would be interesting. When a set of tests on a material has been made, the mean of the results is taken as the best value of the property measured. In physical investigations generally a further step is taken by calculating what is termed the "probable error," which broadly is a measure of the trustworthiness of the results. Calculation of the probable error is troublesome, but Martens has pointed out that the "mean error" is nearly as accurate, and good enough for practical purposes. The mean error is the sum of the deviations of the individual results from the mean, irrespective of sign, divided by the number of observations. The mean error is conveniently expressed as a percentage of the mean value. If the mean error is large, either the method of testing, the uniformity of the material, or the preparation of the test specimens is at fault. Generally the source of the error can be inferred. A large mean

error in tests of steel would indicate want of uniform quality in the material, in cement—probably faults in preparing the test briquettes. Of two supplies of a material, that with the smaller mean error is preferable.

There is another kind of testing, likely in the future to be of increasing importance—that is, the measurement of strains in members of completed structures in order to determine the stresses to which they are actually subjected in service. Some years ago, after the loss of the "Cobra," measurements of the strains in the skin of a torpedo-boat slung in various ways were made at the request of the Admiralty. The object was to obtain information on the stresses in a structure supported on waves. Strain measurements on the members of bridges during the passage of trains have been made in Holland, in France, by Mr. La Touche and Mr. Sales in India, and by Professor Turneaure in the United States. These observations throw light on two points—the trustworthiness of theoretical calculations of the stresses and the magnitude of the stresses due to dynamical actions which cannot be calculated. Recently Mr. I. E. Howard, Engineer-Physicist at the Bureau of Standards, has initiated a very extensive investigation which is to extend to large bridges, the Panama lock-gates, and steel-framed buildings. Some results obtained by him on the stresses in the shell of a simple cylindrical tubular boiler have been published. A cylindrical boiler shell is a very simple structure, and the straining action is statical. It might be expected that theoretical calculations of the stresses would in that case be approximately verified by the observations. In fact it is not so. The distribution of stress is very much less uniform than it is assumed to be in theory and in the design of boilers. Of course, this is chiefly due to angle-irons and joints, which in most cases reduce the stresses, but, at any rate, greatly modify the stress distribution.

I should perhaps apologize that I have not put before you the usual kind of Address. I could not avoid looking at our own affairs in the light of present events. We are involved in a tragedy, which is not less a tragedy because we believe we have

acted deliberately, rightly, and without malice. Not less a tragedy because we believe that our cause is good and will prevail. Sooner or later, peace will come, and with it a changed and, we trust, a better Europe. We shall have to repair the material devastation and reconstitute the moral checks on the brutal exercise of military power. I hope we shall be able to say, in the spirit if not literally, what Euripides said of Athens: "Ours is an old and happy land, which no conqueror has ever subdued; its children walk in clear air, and wisdom is the very bread they eat."

Vote of Thanks.

Dr. William H. Maw, *Past-President*, said he regarded it as a very great privilege that, as the senior Past-President present, it was his pleasant duty to propose a very hearty Vote of Thanks to Dr. Unwin for the Address to which they had just listened. The Address was one of exceptional interest and value. It was particularly valuable, inasmuch as it laid before the members the considered opinions of one who had devoted his whole life to the advancement of engineering. Dr. Unwin, at the conclusion of his Address, had apologized for not giving what he called the usual type of Address. He (Dr. Maw) thought, however, that no such apology was needed, but that, on the other hand, the members would specially thank Dr. Unwin very much for not having done so. They were all delighted to hear Dr. Unwin's opinions upon the various points of national importance which he had put before them. The Address was one which would be read and re-read. To those present, who had listened to it, it was unnecessary for him to say more. He would therefore at once formally propose that the most hearty thanks be given to Dr. Unwin for the Address which he had delivered.

Mr. Michael Longridge, *Vice-President*, said it gave him much pleasure to second the Vote which Dr. Maw had proposed. He had learned a great deal from Dr. Unwin, who was the master while he was the scholar; and he felt it a high privilege to be his colleague on the Council.

Dr. Maw said the Vote which he had proposed, and which Mr. Longridge had seconded, was one which Dr. Unwin could not very well put to the Meeting. He would therefore ask the Meeting to pass the Vote by acclamation.

The Vote of Thanks was passed with acclamation.

Dr. Unwin said he was very proud indeed to be the President of the Institution. The thanks which had been given him were quite adequate reward for any trouble he might have taken in producing the Address. As they would have noticed, he had not been quite complimentary to British methods and activities, and he was not quite sure whether he might not have trodden on the toes of some, but at any rate what he had said he sincerely thought, and what was wrong in the Address would no doubt be overlooked. He thanked Dr. Maw and Mr. Longridge for the kind way in which they had spoken of the Address, and he thanked the Meeting very much for the way in which they had received it.

HISTORY OF THE METALLURGY OF IRON AND STEEL.

LECTURE

By Sir ROBERT A. HADFIELD, D.Sc., D.Met., F.R.S.,
Member of Council,

AT THE GRADUATES' MEETING,

Monday, 8th February 1915.

W. Cawthorne Unwin, LL.D., F.R.S.,
Vice-President, in the Chair.

Introductory Remarks.

Having been requested by the Council to deliver the Graduates' Annual Lecture for this year, the author has selected as his subject "The History of the Metallurgy of Iron and Steel." If it had not been for the War, which has brought heavy demands upon his time, he would have liked to give a more complete Lecture than that offered this evening. He begs, however, that, under the circumstances, any shortcomings in it will be excused.

In opening the subject, the author would first say that it is a great honour to him to be asked to lecture before this Institution, which has done so much to forward technical progress, not only in Great Britain, but throughout the Empire. The Institution numbers some 2,700 Members, 3,000 Associate Members, 50 Associates, and 600 Graduates, about 6,400 in all. The careful

manner in which the Council deals with new applications for membership ensures the continuity of the high quality of the work of the Institution. The Graduates of to-day are the Members of to-morrow, and those present to-night will help to shape the future of this country in regard to the science of Mechanical Engineering, a science which is playing such an important part in the event that preoccupies everyone so greatly—the War.

On the illustrious roll-call of Past-Presidents there are the names of those who have helped to make the mechanical arts famous, not merely in Great Britain, but throughout the world. The renowned George Stephenson was the first President; then followed Robert Stephenson, Fairbairn, Ramsbottom, Whitworth, Penn, Napier, Siemens, Hawksley, Bell, Anderson, White, and others who are happily still with us. A proud list, and yet it is hoped there are those present who may reasonably hope that one day they will have done such excellent and original work as shall entitle them to have their names also inscribed on this roll of honour. It is the Graduates who must sustain the reputation of, and add fresh lustre to, the work of the Institution. The author would here add that the Institution owes much of its success to the untiring energy on its behalf, of its Secretary, Mr. Worthington. The author has known him for many years, and has never seen him fall short in anything concerning the interests of the Institution. His absence to-night, owing to family illness, is much regretted.

Although a metallurgist rather than a mechanical engineer, the author would point out that the two sciences work hand in hand. Metallurgists claim to be ahead, because without their products there would be little or no mechanical engineering. It is the mechanical engineers who take the iron and steel products of the metallurgist and work them into more finished forms; it is they also who help to produce appliances by means of which these products can be manipulated and dealt with more rapidly, on a larger scale, and their quality improved and perfected.

The Institution in the past has always wisely encouraged the metallurgical side of mechanical engineering, by its Special Committees devoted to metallurgical subjects. One of its latest

Committees, over which the able President-Elect, Dr. W. Cawthorne Unwin, F.R.S., presides, is devoting its attention to the question of Hardness. It is hoped the results will be of great benefit not only to the mechanical engineer, but also to the metallurgist. The Alloys Research Committee, established in 1889, has in the past done most excellent work, with which are connected such names as Anderson, Roberts-Austen, Gowland, Arnold, Stead, Harbord, Unwin, Huntington, Wrightson, and others.

Of recent events, hardly anything can have given greater satisfaction to the Council and Members of this Institute than the wise order of the Admiralty, that engineering officers in the Navy are to be classed as part of the Military Branch of H.M. Navy, with its consequent higher ranking and position. It has always been incomprehensible to the author why the technical man has not in the past received more full and just recognition by both our Services. Whilst the highest degree of admiration is given to the brave men forming the fighting side of the Royal Navy, credit is equally due to the engineering officers, of whom no less a Naval authority than Lord Fisher has recently said, when speaking of this new regulation: "The unapproached efficiency of our engineers in the Navy has long since merited this tardy recognition of their all-important part in the present splendid fighting condition of our whole fleet . . . the unfailing propellers get us away at top speed on the spot almost to a minute, even though it be several thousand miles away." Every Briton heartily supports this commendation. Proud as we are of our soldiers and sailors, we are not less so of our sailor-engineers. One of the most distinguished Admirals, Sir David Beatty, pointed out not long ago that the engine-room staff forms one of the Navy's most important adjuncts, and that he had recently specially directed the Admiralty's attention to this. We have, too, the recent death—sad but glorious—of one of our members—a most brilliant officer—Engineer-Captain C. G. Taylor, who died fighting for his country. The author would suggest that, as a mark of respect, we all rise in our places.

Turning now to the subject of metallurgy, it will be found that the problems this science involves relate in the main to physics

and chemistry, although their solution requires the constant co-operation of that branch of the science of mechanics for the advancement of which this Institution exists. The problem of the alloys of carbon and of many different elements with the world's leading metal—iron—is extraordinarily fascinating. Iron is in every sense the world's leading metal. It is constantly used for an immense variety of purposes; yet we all recognize that it still embodies a vast number of secrets—it still affords a wonderful field for research. "He who holds the iron of the world rules the world" is a proverb still quite true.

Early Metallurgy.—One can picture the joy of the earliest metallurgist when he discovered that a lump of red-looking earthy substance tossed by accident in his fire gave quite another material—a "metallic" product which could be made to cut. This first member of a prehistoric Iron and Steel Institute was not long in recognizing the far-reaching consequences of his accidental discovery. He, no doubt, first made weapons—a crude type of javelin, presumably—from this new product, but appalled at the rate at which the men of his period had become able to destroy one another by reason of this discovery of his, he probably endeavoured to counteract the action of the new offensive weapon he had been able to put in their hands, by providing them with means of defence, and he gave them "metallic" shields. By that time, however, others had entered the field and started to produce both classes of weapons, making each alternately the stronger, and so matters progressed. The first metallurgist was thus indirectly also the first man to initiate the "projectile versus armour" conflict, a conflict which has continued ever since, is being continued to this day, and one in which the author ventures to think his own city of Sheffield has acquired world-wide renown. The population of Sheffield in the year 1745 was about 42,000, and it has now increased to about 460,000. Photographs from engravings of Sheffield in 1745 and 1819 show the progress made. Lantern slides are shown of a portrait of Huntsman, the son of the Benjamin Huntsman who, more than any other man, was instrumental in introducing crucible

steel, and of the cementation furnaces built by Benjamin Huntsman about 1750.

The author has dealt fully with metallurgical products of comparatively early date, going back some fifteen or sixteen centuries, in his Paper to the Iron and Steel Institute, "Sinhalese Iron and Steel of Ancient Origin," read in May 1912. Thanks to the kindness of Mr. J. H. Marshall, C.M.G., C.I.E., the Director-General of Archæology in India, the author has been able to obtain a specimen from the oldest metallurgical monument known, the world-famous Delhi Pillar, which is about 24 feet in length and weighs $6\frac{1}{2}$ tons. It was found to have the following composition:—

C.	Si.	S.	P.	Mn.	Fe.
0·080	0·046	0·006	0·114	nil	99·720

The specific gravity was 7·81 and the Brinell ball hardness number 188. This is probably one of the finest and most unique specimens of ironwork ever produced until modern times, and great credit is indeed due to the Eastern metallurgist who worked up such a specimen of his art. The author dealt with the manner in which this was probably accomplished, in the Paper already referred to.

Before concluding this subject, the author would like to show a specimen of ancient steel of unusual value and interest, taken from the Khan Baba Pillar. It is probably the first to be exhibited in modern times, of an ancient piece of high carbon steel which has been hardened by quenching. The following is the analysis of its composition:—

C.	Si.	S.	P.	Mn.	Cr.	Ni.	Fe.
0·70	0·04	0·008	0·020	0·02	trace	trace	99·5%

The specimen weighed about 8 oz., was 3 inches in length, $2\frac{1}{2}$ inches in breadth, $\frac{1}{2}$ inch in thickness, and showed a fine crystalline but rather brittle structure. After removing the scale, the Brinell ball hardness number was found to be 146. On being cut through with a saw, there was a fair proportion of the original metal still unoxidized. It was received a few months ago from the Superintendent of Archæology in Western India, Mr. Bhandarkar. Of the large number of samples of ancient iron and supposed steel the author

has examined during the last few years, not one has contained sufficient carbon to be termed steel in our modern sense. This specimen has been in its present condition for probably more than two thousand years, and yet after being heated and quenched, hardens exactly as if it had been made only yesterday, thus showing that in this long interval, beyond surface oxidation, it has undergone no secular change of structure, or alteration in the well-known capacity of an alloy of iron with carbon to become suddenly possessed of glass-scratching hardness after being heated and quenched in water or other cooling medium. The photomicrograph of the material in the original condition "as received" shows pearlitic structure, and consists of elongated and irregularly disposed crystals of sorbitic pearlite upon a ferrite ground mass. The specimen has evidently not been reheated above the Ac_1 point since it was deformed. The crystallization varies from fine to coarse. In places the structure is blurred, as a result probably of mechanical work. The carbon is not uniform, varying from 0·30 per cent. to 0·75 per cent. There are seams of slag visible; apart from these the material appears to be of similar type to ordinary modern carbon steel. The structure after being quenched from 850° C. in water is Martensitic. Although the specimen was small—about 7 mm. by 4 mm.—yet the quenching has not been successful in preventing a small amount of troostitic structure from developing and somewhat destroying the definition of the Martensitic needles by darkening the ground mass. On the edges where no troostitic structure develops, the specimen will scratch glass.

This bar was found at the bottom of the stone pillar, and dates back to about 125 B.C. Mr. Marshall, the Director-General of Archæology in India, was present when the base of the column was excavated, and affirms that, from all he saw, the column could not have been shifted at a later date, nor could the bars found have been subsequently inserted.

The column itself is locally known as Khan Baba. On this is an inscription recording that it was a Garuda-dhvaja erected in honour of the god Vasudeva—that is, in front of his temple.

Garuda is more or less a fabulous bird, and is believed by the Hindus to be the vehicle of that god. Garuda-dhvaja means a pillar surmounted by the figure of Garuda, and such pillars are generally put up before temples dedicated to Vasudeva. The inscription shows that the pillar was erected by a Greek called Heliodorus, son of Dion, who was an ambassador despatched by the Greek King Antialkidas, King of Taxila, to the court of an Indian Prince named Bhagabhadra, who ruled over Central India.

Whilst Mr. Bhandarkar thinks that the bars in question were chisels, it is more than probable they were really wedges, being inserted to steady the column, especially as they were found between the base of the column and the first foundation slab. The specimen examined is folded over and thinned out at the edges.

French Metallurgy in the Eighteenth and Nineteenth Centuries.— Two remarkable books were published in 1846, one "L'Art de Tremper les Fers et les Aciers," by M. Camus, and the other, "Mémoire sur la Fabrication et le Commerce des Fers et Aciers dans le Nord de l'Europe," by M. F. le Play. That by M. Camus deals in a most practical way with the methods required to obtain the best qualities from steel which has to be hardened and tempered. Much of the information he gives is quite as applicable to-day as when it was first written. Professor le Play shows how, for a hundred years or more, French metallurgy, as regards the production of high-class steel, had been entirely misdirected by the idea to which French metallurgists obstinately clung for so long, that it was possible to produce in France bar iron for making steel of the same quality as produced by Sweden, this, too, in face of the wonderful progress then made by the English steelmakers, who had wisely adhered to the importation of high-class Swedish irons.

Numerous works in France failed because of the obstinacy with which the French clung to their methods of trying to utilize their own Empire's products at the expense of quality. Even when works were started, as, for example, those of Aciéries de Nerouville in 1770, where Swedish iron was exclusively used, special pressure

was brought to bear to compel them to discontinue using the imported product, researches being renewed in order to try and utilize French iron, again only with the same disastrous consequences. Professor le Play further points out that it was Réaumur, in 1722, who misled those engaged in the industry. But for this the manufacture would have developed, as in England. It is probable that the development would have been successful, since, during the whole of the eighteenth century, England believed taxes should be laid upon the right of importation of foreign iron.

This question has been dealt with at some length, because it is interesting to see that British common sense and practical way of regarding matters of this kind kept Britain on the right road. It was good judgment of no little value, for it resulted in Sheffield becoming the centre of the special-steel trade of the world, a position which that city still holds. The French idea was that the quality of the material then known as "body" was to be obtained by purifying the products of their more imperfect ores. But this was not practicable, and Sweden is still the storehouse for the production of the purest quality of raw material. There is more Swedish pig-iron and bar-iron now being used than at any previous time. Le Play also mentions (and in view of Faraday's and Stoddart's experiments in 1820, this is specially interesting) that these experiments commenced owing to Faraday having analysed certain specimens of material from India known as Wootz steel. A similar series of experiments was then undertaken in France. Assistance was given to the project by the well-known Société d'Encouragement pour l'Industrie Nationale, a Society still existing and doing really excellent work. This Society found the necessary funds for carrying out some three hundred experiments upon alloys of iron with different metals, and granted gold medals to several investigators in the art of steel-making. A report was presented to the Society in 1821, and the experiments continued until the year 1824, but did not appear to result in any practical benefit.

Metallurgy in the Middle of Last Century.—In the early days of the nineteenth century Michael Faraday, whose whole life was one of

untiring energy, devoted a certain amount of attention to the study of metallurgy, and in 1822 he mentioned in one instance that he could not go to Sheffield, where he intended to have his alloys made in continuance of the experiments he and Stodart had started at the Royal Institution, but that he was carefully preparing in London the mixtures to be melted in Sheffield, placing them in separate parcels. The work was to be given to a trusty assistant, who was to go down and see the experiments put in hand and completed at Sanderson's works, a firm which is still in existence to-day. Faraday foresaw that metallurgy was destined to become one of the leading branches of science, and that in a general way it was upon progressive metallurgy that most of the advances in modern effort and progress were dependent. He may thus be regarded as having been a pioneer in modern metallurgical science no less than in those branches with which his name is more intimately associated.

A most valuable work was issued in 1867, namely, Kohn's "Iron and Steel Manufacture," the best of its kind for almost a generation, and for the origin of which we are indebted to those who have given us the modern and most valuable technical journal known as *Engineering*. The above served as a text-book for over twenty years, and now remains of much historical interest. It gave amongst its 270 pages not more than about half a dozen references to metallurgical Papers. How little this seems when compared with the special literature now available! Take, for example, the Journals of the Iron and Steel Institute, containing, as they do, annually about one thousand pages of original matter, consisting of Papers with the discussions thereon, and about five hundred pages more of notes showing the progress made in the home and foreign iron and steel industries; they afford an illustration of the huge step forward which has been made in this direction since the "Sixties."

Again, there is the work of Dr. Percy, which is a classic; even now one can obtain valuable knowledge and aid from it. His careful and well-prepared descriptions of plant, processes and research are still of high value, and must have been specially

appreciated when so little knowledge existed on the subjects he dealt with. Dr. Percy devoted some consideration to the alloys of iron. His master mind, like that of Faraday forty years earlier, saw some of the possibilities of these combinations of iron with various elements. Unfortunately, Dr. Percy's alloy experiments were most of them on such a small laboratory scale that the results obtained were more of academic than of practical value. The whole of his observations with regard to what is probably the most important of the iron alloys, namely, iron and manganese, are summed up in a few lines: "We have already," he says, "considered carburized alloys of iron and manganese, but the presence of carbon, it need hardly be remarked, may be expected to modify the properties of any alloy in a material degree. With regard to alloys of pure iron and pure manganese, I do not know whether anything satisfactory has been published; I have not met with anything of the kind." This statement was indeed prophetic.

Naturally, the highly-carburized alloys of iron and manganese to which Dr. Percy referred were really Spiegeleisen, containing at the most 7 or 8 per cent. of manganese. There were but few ferro-alloys made before about 1865, and those which were produced contained high percentages of carbon, the presence of which completely altered the character of the product. This was the reason why the properties of the extraordinary alloy now known as "manganese steel" were disguised and masked under the predominance of the carbon present in the manganiferous alloys formerly produced. Thus the production and manufacture of an alloy which has proved of such great advantage to mankind remained hidden for another twenty years. It was the discovery by the author of this particular alloy, about thirty years ago, which may be truly said to have initiated the first systematic study of alloys of iron with other elements. Mushet had made what was then termed self-hardening alloy steel, but its manufacture was shrouded in mystery and its application comparatively small. Moreover, its qualities were more in the nature of a superior cast-iron than of steel.

The Conservation of New Resources.—The investigation of alloys of iron is exceedingly important and of great practical benefit and utility, not only from the point of view of obtaining the required combination for a given purpose, but also from that of obtaining for a given quantity of metal the maximum degree of utilization. The world's resources in the matter of iron ores are not inexhaustible, and it may be incumbent upon us before long to husband them more carefully. The United States in 1913 produced no less than thirty-three million tons of pig-iron, Germany twenty million tons, Great Britain, France and Belgium nearly as much more, all involving enormous consumption of iron ore. Notwithstanding that Great Britain has now fallen to the third place in the production of pig-iron, we were never so prosperous. Mere tonnage production by our rivals is not entirely an index, so long as we have cheap sources of supply whence the ore or the pig or bar iron can be obtained. These few remarks have been written to show that any temporary heading of the list of nations producing pig-iron cannot by itself alone be considered. There are many other factors. It must be remembered, too, that, as in the past, the production of iron by different countries must vary from time to time. The country leading at one period may not necessarily do so for all time. The great point is to provide for a source of supply of the ore.

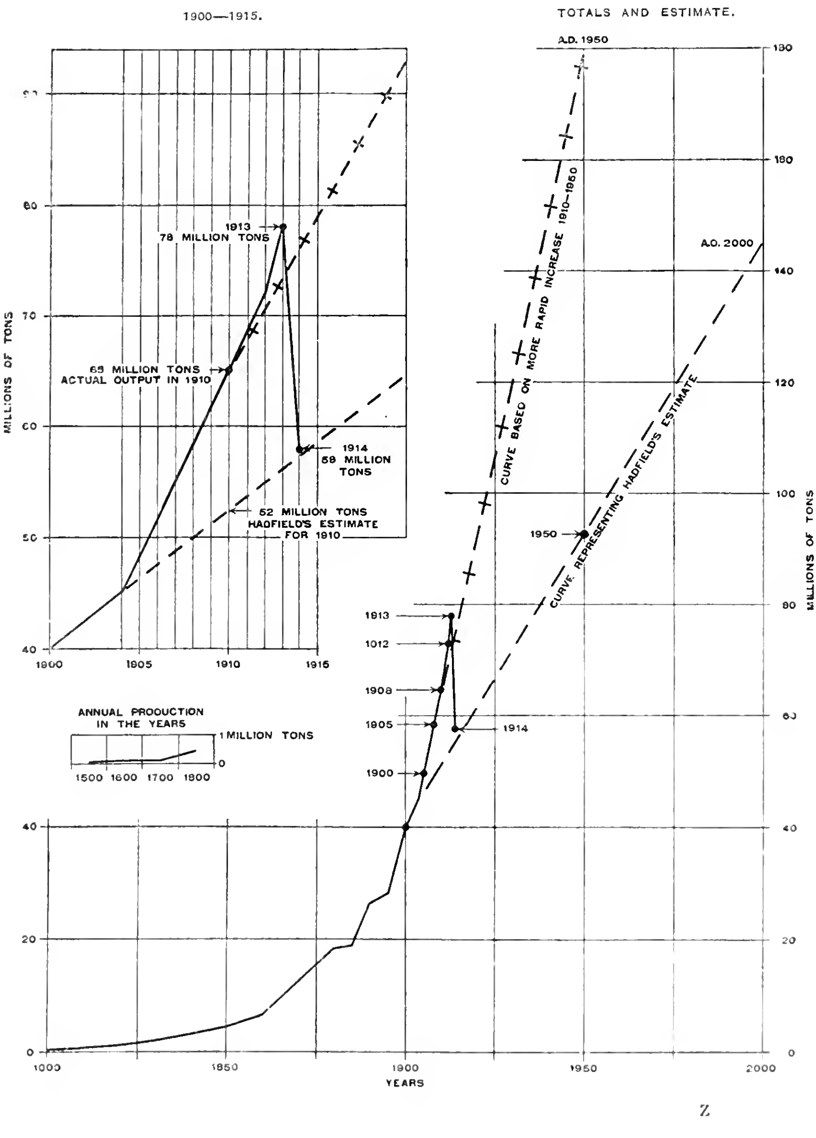
The well-known French writer, Henri Gaston, in his interesting brochure, "Où va l'Allemagne?" points out that Germany will in the near future exhaust her own supply of iron ore; then what is she going to do? She has not outside sources of any great value. Without introducing politics, perhaps there was more than met the eye in Germany's interest in Morocco, with its great stores of iron ore, while the ore-value of the French territory now the scene of such heroic struggles is second to no other in the world. Gaston claims that France has a great and important metallurgical future. He goes so far as to say, "Nous sommes destinés, si rien ne vient contrecarrer nos desseins, à devenir la nation métallurgique la plus puissante du monde." This conclusion is one which it remains for the result of the present War to settle definitely.

It may also be pointed out, with reference to the enormous increase in production which has taken place, that in the curve given in his Presidential Address to the Iron and Steel Institute in 1905, the author there expressed the opinion that the total pig-iron output, at that time about 46,000,000 tons, would in 1910 probably reach 52,500,000 tons. As a matter of fact, this was considerably under the mark, for the actual output for 1910 was 66,000,000 tons, and for 1913 78,000,000 tons, Fig. 1. Thus, in even the short space of nine years since that Address was given, the world has advanced much more rapidly than the most sanguine could have thought possible. Where will it stop? "The curve surely cannot proportionately advance at this enormous rate." These were the author's words in 1910. A halt has been now called, owing to the War, and not only has the output for 1914 dropped nearly one-third, but 1915 will probably see a still further drop. In fact the production seems to be coming back to about the position shown by the author's curve. There is no doubt that the world has been going too quickly, and that the curve was a fast and unnatural one.

The Author's Research Work.—In describing the important branches of science—metallurgy and mechanical engineering, for the two are associated—the author thinks it will not be out of place to refer to his own researches, for the reason that when these commenced in 1882 little was known on the subject of alloys of iron. In fact, in the light of our present knowledge, one might safely say that the subject was practically an unknown one. In describing the history of this particular development, and by use of such references, the author will therefore give some general idea of what has been done in the past, and what led up since his first Paper on "Manganese Steel" in 1888, to the marvellous progress in alloys of iron with other elements.

The researches have been fully described in sixty-five Papers published between the years 1884–1914, and submitted to various Scientific Societies in Great Britain, America, France, Germany, Russia, and elsewhere, with regard to—

FIG. 1.—*The World's Production of Pig-Iron, from the beginning of the Fifteenth Century.*



(*a*) Manganese steel.
(*b*) Low-hysteresis steel.
(*c*) Iron alloys of many different types, including nickel, chromium, tungsten, cobalt, silicon, aluminium, molybdenum, and other elements.
(*d*) Low temperature investigations on iron alloys of about one hundred different types.
(*e*) Electrical and magnetic researches.
(*f*) Production of sound steel.
(*g*) General research work.

For want of time it will only be possible to deal with one or two of the main discoveries: (*a*) manganese steel; (*b*) low-hysteresis steel. Owing to the nature of these peculiar alloys, the difficulties attending their introduction, and the wide ground they cover, many years were necessary to develop them. It has therefore only been within a comparatively recent period—that is, during the last ten years—that they have come into general use on a large scale. The initial obstacles against introducing new products in metallurgy and engineering are generally great, and the road the author had to travel as a discoverer has not been less stony than that of his predecessors in this and in other branches of science. For example, the extraordinary hardness of manganese steel for many years prevented its wider use, until methods had been devised to deal with this and other difficulties met with, due to the physical characteristics of the material.

In the case of low-hysteresis steel, not only had manufacturing troubles to be overcome, but entirely new designs of machines had to be introduced to take advantage of the wonderful qualities of the material. Older types of machinery and apparatus had to be abandoned, new designs substituted, naturally involving delay and time before the advantages of the material itself could be obtained. The world in general is now largely benefiting by the use of these discoveries; in fact, take them both away, and certain types of engineering and modern electrical practice become practically impossible. To give some idea of their importance, it may be mentioned that there are now several million pounds sterling of these products being made annually.

Manganese Steel.—Before the author's discovery, it was thought that when making an addition of more than about 2 per cent. of manganese in steel, a brittle and useless product would result. This was quite true, but the author's researches showed, strange to say, that by increasing the manganese to the high percentage of about 12 per cent., a product could be obtained which, after quenching, possessed exceedingly high tensile strength and at the same time wonderful toughness, as the various specimens exhibited show to be the case. Another peculiar property of the material was found to be its non-magnetic qualities, notwithstanding the presence of such a large proportion of iron. Since the discovery of the material, this non-magnetic quality has interested most of the leading scientists of the day, including Lord Kelvin himself, who stated frankly that he was then unable to offer any explanation for it. There is not time to describe this peculiar material in detail, but its qualities have been dealt with very fully in the author's various Papers on the subject.

A few of the present applications of manganese steel were shown by lantern, as follows:—

The first manganese-steel rails ever rolled, namely, in the years 1904 and 1907; drill tests giving the comparative hardness of manganese steel as compared with carbon-steel, Plate 3; a forged test bar of mangauese steel, Fig. 2 (page 333), which showed a breaking strength of 65 tons per square inch, with an elongation of no less than 57 per cent. measured on 6 inches, about two and a half times the tensile strength of mild steel, and 50 per cent. more ductility; drop-tup tested manganese-steel rails; a section of rails exactly the same as that at work in Paris, Plate 4, during the last six years; a manganese-steel layout which has been in service in Sheffield for six years. The layout was then taken up to be replaced, but could have been used for another six or eight months; in fact, a considerable portion would have been serviceable for several years longer. As layouts of ordinary steel had to be replaced in less than a year, it will be seen that great economy can be effected by the use of such material; manganese-steel crossings at work in London at the British Museum Station, Plate 6. These have been in service upwards of twelve years, and during this time no less than 600,000,000 tons of traffic have passed over the crossings. It is estimated that they will last at least two or three years more.

These results show the great importance to the engineering world of this valuable material. Instances could be multiplied by

the thousand and one applications of the product, which the author described in his Paper to the Institution of Civil Engineers in 1888, upon which he had been working for several years previously.

Low-Hysteresis Steel.—This steel, which was invented many years ago, has been found exceedingly valuable for electrical purposes, chiefly for making transformers, Plate 5. It is termed low-hysteresis steel for the following reason:—Some years ago it was found that the energy losses in iron or mild steel used for transformers were very considerable. In other words, there was, so to speak, internal friction in the molecules of the iron, upon the constant reversal of the electrical energy. This friction or lag has to be overcome each time the wave of energy is reversed, thus causing loss of energy, or, as Sir Alfred Ewing calls it, "hysteresis loss." Wrought iron or mild steel, although the best material for the purpose, not only possesses considerable lag, but the hysteresis losses grow worse in use, sometimes doubling in a few months. This is termed "ageing."

The author produced an alloy of iron and silicon, the latter element being present in quantities 30 to 40 times in excess of that usually existing in ordinary steel and the carbon under 0·10 per cent.; its composition has been fully described in various Papers. After suitable heat treatment, the material was found to be not only of such a quality as avoids a very large proportion of the energy losses, but is also quite stable and does not age. Consequently the transformers in which it is employed remain practically constant after working for any length of time. In former days the energy losses were so serious that the sheets or plates of which the transformers were composed had from time to time to be taken out and annealed. If this was not done, the energy losses rose up to the high figure of 10 to 15 per cent., with its accompanying huge increase in the coal bill.

The following is a brief *résumé* of the qualities of the low-hysteresis material:—

(*a*) By its small energy losses, Fig. 3, whether in hysteresis or eddy current losses, the latter due to the high electrical

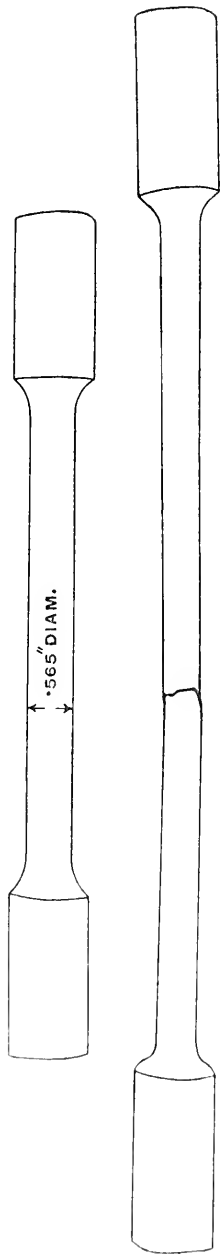


Fig. 2.—*Manganese-Steel Forged Test Bars, 6 inches parallel* × 0·565 *inch diameter.*

Broken Bar gave a Tensile Strength of 65 tons per square inch with an elongation of 57 per cent. on 6 inches.

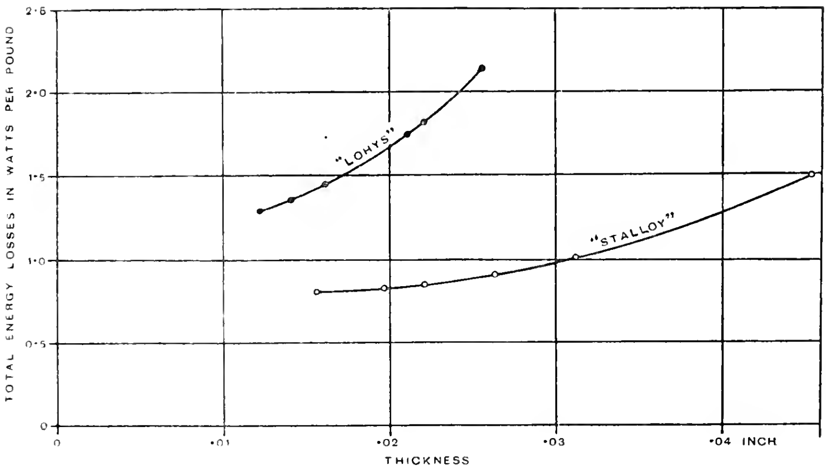
resistance of the material, the output of transformers is increased no less than about 50 per cent., without any increase in dimensions, weight, or higher cost of labour.

(*b*) The heating effect is greatly reduced, with a corresponding reduction of the accompanying energy losses.

Fig. 3.—*Comparison of total Energy Losses in Sheets of various thicknesses between Low-Hysteresis Material "Stalloy," and "Lohys."*

Illustrating the reduction of Loss of Energy by using the Hadfield Low-Hysteresis Material, "Stalloy" (made by Messrs. Joseph Sankey and Sons, of Bilston). These curves include both Hysteresis and Eddy Current Losses.

β 10,000, 50 ~.



(*c*) The windings are of fewer turns and larger section, also less copper is required.

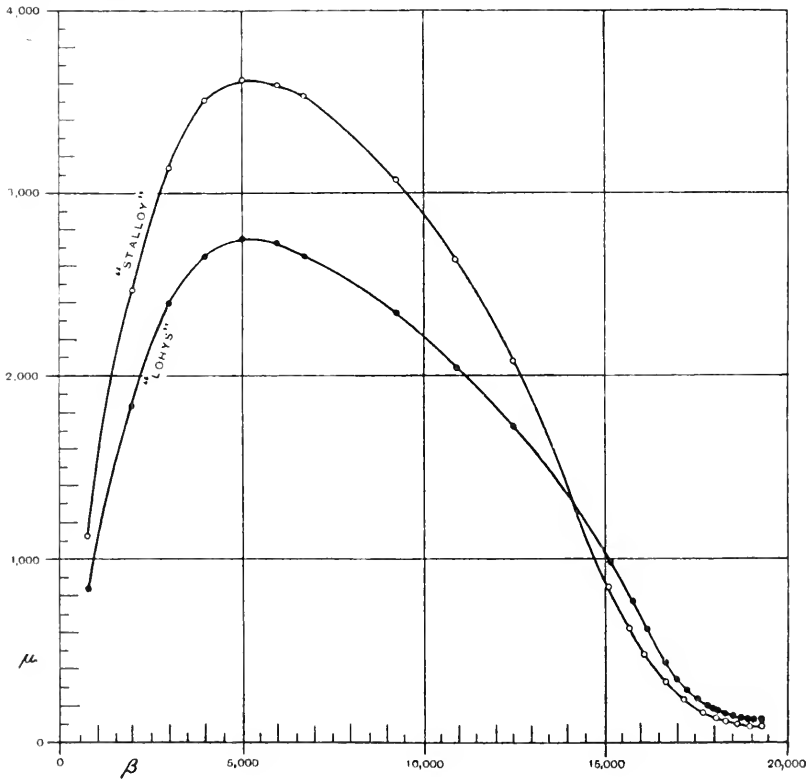
(*d*) The value of the transformer is considerably increased, even after allowing for the somewhat higher cost of the material used.

(*e*) The eddy current losses are so small that there is no advantage in using sheets thinner than 0·02 inch, thus reducing the space used for insulation, and lessening labour in construction.

(*f*) Its permeability is higher than that of "Lohys," the best ordinary steel hitherto used, throughout the range of magnetization used in transformers, and in non-ageing properties it is superior to this material, Fig. 4.

Fig. 4.—*Comparison between Low-Hysteresis Material "Stalloy," and "Lohys."*

Showing, by μ-β curves, the Permeability of "Stalloy" and of "Lohys," and illustrating the superiority of the former up to β 14,000, which fully covers the range of the Transformer Work.



The number of parts per year built by the Westinghouse Co. of America alone, who along with the United States Steel Corporation and the General Electric Co. manufacture the material in America, increased from approximately 32,000 with 450,000 k.v.a.

in 1903, to approximately 60,000 with 843,000 k.v.a. in 1911. This is the latest year for which the author has obtained the output figures. The total kilowatt capacity of the transformers shipped by the Westinghouse Co. in the nine years above mentioned approximated to 5,500,000 k.v.a. There is also the production and use of this low-hysteresis steel by the other maker, the General Electric Co. of America, which, in the nine years referred to, produced 7,500,000 k.v.a., and other makers 1,000,000 k.v.a., the total k.v.a. in service of the low-hysteresis material being approximately 14,000,000 k.v.a. These figures refer to 1910, and for America only. Since then the total has increased probably 50 per cent. both in this country and on the Continent.

In regard to (*e*), it may be pointed out that since eddy currents contribute to the core losses, it follows that, besides reducing hysteresis losses, it is also desirable that the material employed should have a low conductivity. That this further condition is fulfilled by the low-hysteresis material is shown by the fact that the eddy current losses are so small that there is no advantage in using sheets thinner than previously found necessary.

The importance of the invention can best be illustrated by the approximate statement of the very large saving resulting from the use of the material. This saving goes on quietly day and night, whenever the transformers are being used. In April 1910 Professor Morton G. Lloyd, in a Paper read before the Franklin Institute, Philadelphia, estimated that during the previous twelve months the use of this low-hysteresis material had effected a saving in America alone of something like 10 million dollars annually. This figure has since been greatly exceeded, probably doubled. In Great Britain, Germany, and other countries the savings effected have been proportionately as large.

The first transformer made of this low-hysteresis material, Plate 2, was produced by the author in October 1903. It weighed about 30 lb., and was constructed by the Sheffield City Corporation Electric Light and Supply Department. The Sheffield Corporation followed up this experiment, and ordered a 40 kw. transformer, the weight of material used being 830 lb. The transformer was

completed and tested on 9th June 1905, and has since been continuously in use. The magnetizing watts required in this transformer are only 176, or less than half the watts required when using an equal amount of the best transformer iron obtainable. A comparison of a 60 kw. transformer made from this material, with a 40 kw. transformer of ordinary iron, shows the great advantage in size obtained by using the low-hysteresis material. The hysteresis losses are only 0·25 watt per pound at $\beta = 4{,}000$ and 100 frequency; the resistance to eddy currents is five times that of the best transformer iron.

In order to ascertain the ageing qualities of this material, the Sheffield Corporation made special tests on the 40 kw. transformer put to work on 9th June 1905, Plate 5. On 2nd April 1912, Mr. S. E. Fedden, the Manager of the Electric Supply Department, was good enough to furnish the author with the following results:—

Magnetizing Losses of the Low-Hysteresis Material.

Date.	Magnetizing losses in watts per lb.
4th July, 1905	176
4th August, 1905	160
8th May, 1906	150
26th March, 1912	131

In other words, there has been a considerable reduction in the losses. Mr. Fedden stated in his report that he also built a large transformer of this material in July 1905; it took 305 watts, and when last tested on 2nd April 1912 it was only taking 278 watts. The transformers referred to have been in constant use since the day they were built.

It may be added that in addition to a saving in weight of core material, the core weighing only 830 lb. as against 1,120 lb. for a similar transformer using the best transformer iron obtainable, the magnetizing losses of this transformer were only 176 watts as against 238 watts for best transformer iron. It will be seen that not only has there been no ageing, but there is actually an improvement in the core material. This remarkable fact further

confirms its great importance and value. It was estimated that after seven years' service this transformer effected the considerable saving of no less than 8,700 units of electrical energy, equal in value to about £23 11*s.* at 0·65*d.* per unit. In the 60 kw. transformer made in June 1906, Plate 5, advantage was taken in this to reduce its size for this capacity, and it was small enough to go into a 40 kw. tank. The magnetizing losses were originally 305 watts, as compared with 330 watts for a transformer of similar capacity using the best transformer iron. The transformer was put into service in July 1906, and after six years' service it was found that the magnetizing losses had decreased, as shown by the following tests:—

Date.	Magnetizing losses in watts per lb.
8th July, 1906	305
26th March, 1912	278

It was estimated that, after six years' service, this transformer had effected a saving of 700 units of electrical energy, equal in value to close on £1 18*s.* 0*d.* at 0·65*d.* per unit. By January of this year the saving would be about £2 18*s.*, or 1,060 units. It will be seen, therefore, that this development has been of a most important and far-reaching character, and it is difficult to see, until some further great revolution in our electrical knowledge takes place, how such a material can be superseded, for this invention has made an alloy of iron more magnetic than pure iron itself.

Steel Alloys Research.—As regards steel alloys research apart from carbon steel—though even the latter might also be included, as, comparatively, so little was known concerning it but fifty years ago—after carefully looking through the pages of Kohn's well-known work "Iron and Steel Manufacture," very little evidence can be traced of work having been done in this direction. This book has been specially selected as a starting-point, as it were, because it illustrated at the time, and for many years after its publication in 1867, the practical side of thought which then prevailed. At that period no one appears to have given much attention to the effect which numerous elements can have upon

iron, and to the possibilities in store by combining various elements with iron. In its 270 pages, forming a very comprehensive treatise on metallurgy and mechanics, there is not to be found even the faintest forecast of that enormously important development which was shortly to come, by the introduction of what is known as alloy steels.

The same position is shown in the excellent work known as Professor Kerl's "Practical Treatise on Metallurgy," translated and presented by the President of the Royal Society, Sir William Crookes. This now vastly important side of metallurgy was disposed of in only a few pages, under the heading of "The Influence of Foreign Mixtures on the Proportions of Steel."

In spite of all that has since been done, it will be seen that even to-day the field for research is still an immense one, full of difficulties, perplexities, and contradictions. Nevertheless, the advance made in this branch of alloy steels, since the date of the author's first researches in 1882, has been indeed remarkable and of a startling nature.

Whilst it is true there may not be room at the present time for such abnormal discoveries in ferrous metallurgy as in the past, yet workers all over the world are quietly and steadily adding to our stock of knowledge on points, some of which may not seem so important at the time, but all of which tend to enable one to understand better and therefore to control the desired qualities of iron and its alloys. The Alloys Research Committee of this Institution has done excellent work in the past in helping to bring about this development.

Some of the most interesting work of the metallurgist is in the manufacture of armour which cannot be penetrated, and in projectiles which no armour can resist! Whilst both these claims are in one sense correct, in another they are equally incorrect. It seemed to the author that some illustration of the work done by each of these factors in the present war would tend to increase the respect for the great advances made by the metallurgist in the last twenty-five years. Lantern slides were then shown, as follows:—

Two 9·2-inch projectiles after perforating 9-inch hard-faced armour-plate; a 13·5-inch armour-piercing projectile before firing, and another of the same calibre after passing through 12-inch hard-faced armour-plate; a 13·5-inch projectile, so little damaged after perforating a 12-inch hard-faced armour-plate that it could have been ground up, put into the gun, and fired again; a 14-inch armour-piercing shot, also 14-inch armour-piercing shell, the heaps of coal-dust in front representing the respective bursting charges in black powder; a large capacity armour-piercing shell of 12-inch calibre; a 15-inch capped "Heclon" armour-piercing projectile, after perforating a modern hard-faced armour-plate 15 inches in thickness, Plate 6; soft steel caps, Plate 2, squeezed into ring form after being fired, and as recovered from armour-piercing projectiles of 10½-cm. (4⅛-inch) calibre; also projectiles of the same calibre before and after firing; the effect on a hard-faced armour-plate produced by *uncapped* shot, showing the difference between the two types of projectiles, capped and uncapped; the action of caps attached to armour-piercing projectiles whilst perforating hard-faced armour, Plate 2 (this is probably the first time the action of caps has been shown by means of cinema films); a comparison of the energy of a large calibre armour-piercing projectile and that of an express train.

The Striking Energy of Large Calibre Projectiles compared with that of an ordinary Express Train.—To bring this home to the minds of those who are not acquainted with ballistics, the following is given as a comparison:—

One of the Hadfield 14-inch armour-piercing projectiles, weighing about $\frac{5}{8}$ ton, if fired against a modern hard-faced armour-plate, 12 inches in thickness, with a striking velocity of 1,700 feet per second, will then have a striking energy of 30,000 foot-tons. The equivalent range is 11,000 yards, or 6¼ miles. As a matter of fact, it is just possible to perforate a 12-inch hard-faced armour-plate at 15,000 yards, which is 8 miles. An ordinary express train, of four carriages and an engine, weighs 250 tons. Such a train, travelling at 40 miles per hour, or 66 feet per second, has an energy of 14,000 foot-tons, or half the striking energy of the 14-inch projectile referred to above. To make the energy of the express train equal to that of the 14-inch projectile, it would be necessary for the train to travel at the rate of 60 miles per hour, or 88 feet per second. We then obtain practically the same energy in each case.

The relative volume or cubic capacity of the two objects concerned must then be considered. It is estimated that the volume or space occupied by a train—in other words, its cubic

capacity—is about 25,000 cubic feet. A 14-inch projectile, however, only occupies a space of $3\frac{1}{4}$ cubic feet. In other words, the relative cubic capacities are for the projectile $3\frac{1}{4}$ cubic feet as against 25,000 cubic feet for the train—that is to say, the train occupies about 8,000 times more space than the projectile. The object of the foregoing is to show what an extraordinarily fine quality of steel must be required to make the hardened armour-piercing projectile. The projectile is of comparatively small bulk —$\frac{1}{8,000}$th that of the train—yet it possesses the same energy as the express train travelling at 60 miles per hour; in fact, as compared with the train travelling at 40 miles per hour, the shot has twice as much energy locked up in it.

The comparison can be made still more astonishing when it is remembered that the greater part of the energy is, so to speak, concentrated on the immediate point or front of the ogival portion of the projectile, which is only about one-tenth of the bulk of the projectile itself. It will thus be seen that it is not an easy problem to produce an armour-piercing projectile which will impart its concentrated energy upon and perforate the hard-faced plate without itself suffering, unless it is, of course, greatly assisted by the modern hollow cap. In the Hadfield works large numbers of proof projectiles of the capped type—12-inch and 14-inch calibres—can be seen, all of which have satisfactorily passed the ordeal referred to, and yet are none the worse, except for a few scratches on the outside. It will be seen, therefore, that Sheffield continues to maintain its reputation in the world for producing steel possessing the highest qualities of hardness and toughness, the two qualities necessary in projectiles.

Lantern slides were shown as follows:—

Illustrating the effect of the impact of armour-piercing projectiles on hard-faced plates; the front and back of a 14-inch armour-plate 17 feet 6 inches in length, 10 feet in breadth, weighing about 42 tons, also two Hadfield's projectiles of 12-inch calibre, representing the proof "Lot" after perforating this plate; the projectiles striking the plate with a velocity of 2,080 feet per second and 26,000 foot-tons energy, successfully passing the test and being accepted; another heavy hard-faced armour-plate 14 inches in thickness after being attacked by armour-piercing projectiles; the front of an 18-inch

"compound" plate made in 1892 after being attacked by a 13·5-inch armour-piercing projectile, showing the remarkable difference between armour of the old type as compared with hard-faced armour of to-day; an "Era" steel shield for 6-inch gun mounting. Five rounds, comprising 4·7-inch armour-piercing shell, 6-inch common shell, and 6-inch capped armour-piercing shot, were fired against this shield, giving a total striking energy of 8,950 foot-tons on an area of only 13 square feet; an ammunition tube of "Era" steel after being attacked, Plate 6. Another slide showed "War Speed" erection of a new shop at the works of Hadfields Limited, Sheffield. This plant was commenced on 4th November 1914. The illustration showed the work done by 18th December 1914. The total length of the shop is 216 feet and the total area 53,000 square feet, and the shop is already being doubled in size.

Alloys of Iron.—The subject of steel alloys is such an important one in all its bearings that the author may perhaps be permitted to refer here to his earlier Papers, read before this and other Institutions. These Papers give in chronological order the history of this particular branch of the metallurgy of iron and steel. In them the author trusts that full reference and credit have been given to the splendid work done by the many scientists and engineers of all nations who have helped the author in his work, whether in this country, America, France, Russia, Germany, Austria, Belgium, Sweden, Spain, Japan, or elsewhere. As before stated, not a little credit should be allotted to the early work of the Swedish scientists, for first separating for our use many of the elements which we are to-day using in our special steels. It is largely from their work that we are to-day benefiting so greatly.

Amongst other matters, the Papers by the author have dealt with manganese steel and its most remarkable properties; with alloys of iron and silicon; iron and aluminium; iron and tungsten; iron and nickel; iron and chromium; also with a large number of other binary, ternary, and quaternary steels.

It must not be forgotten, whilst dealing chiefly with the influence of one or more special elements upon iron, that the qualities of such alloys are largely affected by the presence of what may be termed the leading element, carbon, which is usually also present. As mentioned later in this Lecture, although in the case of high-

speed tool steel the carbon percentage is not high, its influence is literally enormous, for a reduction of the carbon below certain limits gives a comparatively useless product. Beyond some few exceptions—important ones, it must be admitted, such, for example, as the material known as "ingot iron," "low-hysteresis steel," and some others—all the known "steels," including even mild steel, largely depend for their properties upon the percentage of carbon present, and consequently chiefly upon this element for their commercial value. For example, the wonderful results obtained with nickel-chromium alloys are, to a large extent, also dependent upon certain percentages of carbon, varying according to the purpose for which the steel is required.

Effect of Carbon upon Iron.—In considering alloys of iron with other elements, as just pointed out, the fact should not be lost sight of that carbon holds a position of supreme importance, for its presence even in special alloy steels is, with some few exceptions, absolutely necessary. Take the high-speed tool steel referred to: whilst the carbon present need not be relatively high, yet there must be sufficient carbon present, otherwise the cutting properties of the steel in question would not be attained. The explanation is probably as follows: In high-speed tool steel of modern composition there is usually about 16 to 20 per cent. of tungsten, 2 to 4 per cent. of chromium, and about 0·70 per cent. of carbon. Before treatment of the steel, the carbon exists in the form of carbide carbon and hardening carbon as defined by Ledebur.

	Per cent.
Hardening carbon	0·18
Carbide carbon	0·56
Total carbon	0·74

After treatment, and with the nose of the tool in the condition required for mechanical work, we find the carbon content to have been transformed into

	Per cent.
Hardening carbon	0·60
Carbide carbon	0·14
Total carbon	0·74

Therefore, when recognizing the wonderful effect produced by elements other than carbon added to iron, one must not fail to recognize that most of the new properties acquired by the steel are due entirely to the marvellous change brought out by the form of the carbon present, namely, its transformation from the soft or carbide carbon into what is believed to be the hardening or Hardenite form of carbon. This is the alloy element which enables the steel to retain its cutting properties. Whilst a similar change occurs by heat-treating any low-carbon steel—that is to say, carbon steel without other modifying elements present, or present in very small percentages only—the chromium and tungsten in high-speed alloy steel maintain, or assist in maintaining, the carbon present in the desired form, termed by Dr. J. O. Arnold, F.R.S., "Hardenite," so that the cutting edge does not lose its hardness even when reaching by frictional contact quite a high degree of temperature, which would entirely soften ordinary carbon steel.

The late Dr. A. Ledebur of Freiburg cast much light upon this dark place in metallurgy, namely, the relationship of iron and carbon, and later, still more important work has been done by Dr. J. O. Arnold in connexion with the numerous problems involved.

Low-Temperature Experiments.—Researches in this direction, carried out by Sir James Dewar, have shown that from the behaviour of metals and their alloys, at temperatures approaching absolute zero, there is much to be learned regarding their physical properties and behaviour.

In the joint research carried out by Sir James Dewar and the author, a full description of which will be found in the author's Paper on "Experiments relating to the Effect on Mechanical and other Properties of Iron and its Alloys produced by Liquid Air Temperatures," read before the Iron and Steel Institute in September 1905, it was shown that great increase of tensile strength in steel alloys could be obtained by immersion in liquid air. In one case a tensile strength of over 150 tons per square inch was obtained, not merely from a wire, but from a forged bar.

Recent experiments in America prove that at a temperature of about $-435°$ F., or close upon absolute zero, metals lose their resistance to such a remarkable degree that it would be possible, so it is stated, to transmit the energy developed at one of the larger power houses at Niagara over a quite small metallic wire, simply because resistance vanishes at these temperatures. It will therefore be seen that there is ground for the statement that before long we may have to study not merely heat-treatment effects—that is, an increase over normal temperature—but also treatments below normal temperature.

One of the most important branches of study in metallurgy is that of crystallization. As pointed out in the author's James Forrest Lecture delivered in 1906 before the Institution of Civil Engineers, "Iron is more sensitive, and also has the power of varying its crystallization or form of structure, probably in a greater degree than any other metal. Indeed, the whole art of producing steel of high quality consists in obtaining and controlling the type of crystallization desired."

Our constantly advancing knowledge of heat treatment and the more correct handling of the pyrometer is teaching us to control crystallization, so that we are to-day obtaining the desired qualities of materials with much more uniformity and certainty. The world owes a deep debt of gratitude to the great French metallurgist Professor Henri Le Chatelier, whose practical application of his own researches on this subject has been of the greatest value to the metallurgist. No one, too, has done more than Dr. G. K. Burgess, of the National Bureau of Standards at Washington, D.C., to help on this important phase of metallurgical knowledge.

There are, however, "deeper depths" where apparently even a study of crystallization does not help one. It is quite possible by immersion in liquid air to double the tenacity of pure iron, and yet so far the microscope has not been able to detect the slightest change of structure at this lower temperature. Swedish charcoal iron having a tensile strength of 20 tons per square inch, and 20 per cent. elongation at ordinary atmospheric temperature, possessed a tensile strength of no less than 42 tons when tested at $-193°$ C.,

(absolute temperature 85°), with an increase in Brinell ball hardness from 88 to 223 when tested at the temperature of liquid air. These tests were necessarily taken upon bars of small dimensions, the diameter being $\frac{1}{4}$ inch and the effective testing length 2 inches. The analysis of the Swedish charcoal iron used was as follows:

	C.	Si.	S.	P.	Mn.	Fe.
Per cent. . . .	0·045	0·07	0·005	0·004	trace	99·82

The following were the results of the tests:

Temperature.	Tensile strength, tons per sq. in.
+ 18° C.	20
− 80° C.	27
−100° C.	30
−193° C	42

It may be mentioned that metallic nickel with a tensile strength of 29 tons per square inch was increased to 46 tons per square inch when immersed in liquid air, the elongation rising from 43 to 51 per cent. Increase in "crystalline rigidity" is perhaps the best term with which to explain these extraordinary results. A satisfactory explanation of the facts noticed still, however, remains to be found; in other words, this particular problem is still unsolved.

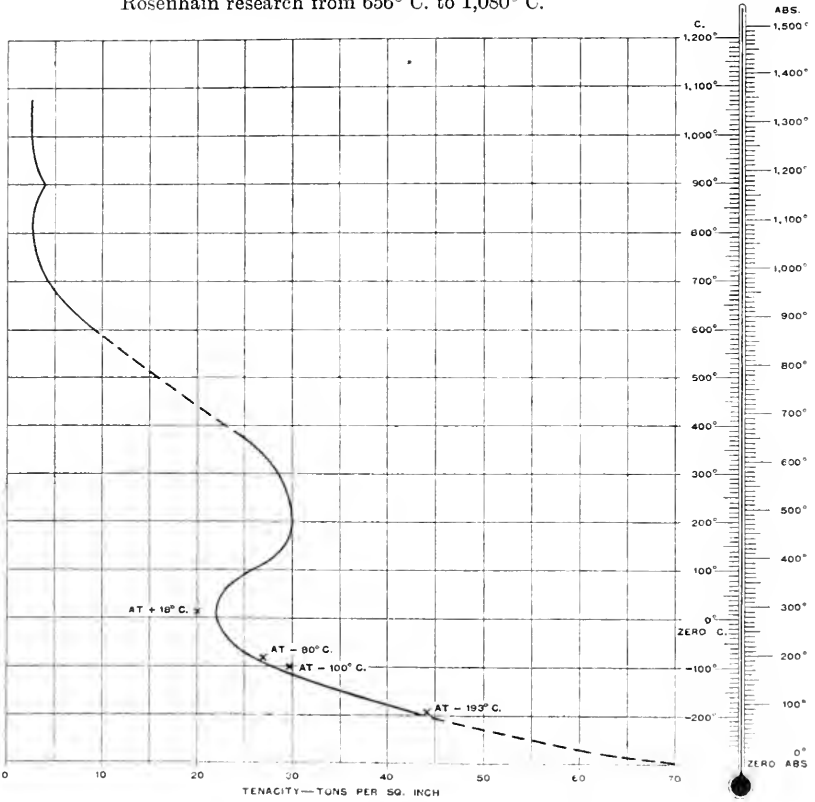
It is important to note that Dr. J. O. Arnold, in commenting upon the author's Paper on "Experiments Relating to the Effect on Mechanical and Other Properties of Iron and its Alloys produced by Liquid Air Temperatures," said that "Diagram No. 36 conclusively proved the newly-discovered properties of iron to be in no way due to allotropic change, as the curve from absolute temperature to absolute zero was smooth and possibly parabolic, the co-ordinates of this curve being maximum stress and breaking temperature."

As will be seen from Fig. 5 (page 347), at absolute zero the estimated tenacity of pure iron might be expected to be about 70 tons per square inch. In other words, the remarkable statement can be made that pure iron at such temperature would have the tensile strength of hard carbon steel. The facts above referred to show

the sensitiveness of iron to changes of temperature "downward." As regards its equal sensitiveness to changes "upward," that is,

Fig. 5.—*Diagram showing the Tenacity of Iron at Temperatures from Absolute Zero to* 1,100° *C.*

Dewar-Hadfield research from Absolute Zero to + 18° C.
Huntington research from + 14° C. to 427° C.
Rosenhain research from 656° C. to 1,080° C.



in the form known as "carbon steel," in some excellent research work by Mr. S. N. Brayshaw, he pointed out that, at certain critical temperatures, a difference of even 1° C. will considerably modify the physical qualities of this material. In other words,

ordinary carbon steel of tool-steel grade, quenched at 725° C., will bend considerably and have a Brinell hardness number of 228. Quenched at 735° C., the same material will only bend 1·5°, the hardness number being increased to 512. Quenched at 740°, or only 5° higher, the bend is nil and the hardness number is increased to the high figure of 713.

Thus we have the remarkable fact that by increasing the range of temperature by only 15° C. we get the phenomenon of complete hardening. The small difference of 15° C. (27° F.), within which range hardening or non-hardening results occur, represents no more than the change in temperature between a spring and a summer day, yet such slight differences in temperature entirely revolutionize the structure of steel.

In the foregoing paragraphs Brinell hardness numbers have been quoted as the factor or coefficient. It should also be mentioned that great credit is due to the ingenious American engineer, Mr. A. F. Shore, for originating the very useful apparatus known as the scleroscope, which he has put at the disposal of the metallurgist for defining and measuring hardness.

Referring now to a somewhat new point, it will be admitted that for a long time it was thought that the tenacity of steel in any ordinary form, such as bars and other similar shapes, could not exceed about 100 tons per square inch. Even this high tenacity has been somewhat exceptional, and has only been produced artificially by special heat treatment, quenching in oil or water. It is true that piano-wire possesses more than double the tenacity just mentioned, and this with plain carbon steel, but the section of such product is so small that it hardly enters into the present discussion.

In the Seventh Report to the Alloys Research Committee on the "Properties of a Series of Iron - Nickel - Manganese - Carbon Alloys," by Dr. H. C. H. Carpenter, Percy Longmuir, and the author, tensile tests of a somewhat remarkable nature were obtained. The experiments were carried out upon nickel steels containing varying percentages of nickel, the tensile strength being taken at the temperature of liquid air, that is −182° C.

Iron-Nickel Alloys made by Hadfield.

Nickel Alloy.	Analyses.						Tests at −182° C. (−295° F.).	
	C.	Si.	S.	P.	Mn.	Ni.	Tensile Strength in tons per sq. in.	Elongation per cent. on 2 in.
A	0·045	0·07	0·005	0·004	trace	—	42·0	Nil.
B	0·48	0·18	0·02	0·02	0·79	1·20	75·4	7·5
C	0·44	0·14	0·03	0·02	0·83	2·15	95·1	12·7
D	0·40	0·14	0·03	0·01	0·82	4·25	75·4	10·0
E	0·42	0·16	0·03	0·01	1·03	4·95	88·0	Nil.
F	0·52	0·10	0·02	0·01	0·92	6·42	142·2	2·5
G	0·43	0·17	0·02	0·02	0·79	7·95	91·1	0·5
H	0·41	0·17	0·01	0·01	0·85	12·22	87·2	—
J	0·45	0·08	0·02	0·02	0·83	15·98	144·2	2·5
K	0·41	0·13	0·02	0·01	0·96	19·91	157·2	15·5

Specimen A (Swedish charcoal iron) is added to represent the qualities of practically pure iron; this, of course, contains no nickel. The specimens marked F, J, K in the Table showed most remarkable tenacities. All the bars were magnetic before and after testing, with the exception of K, which was only very slightly magnetic before being tested in liquid air; after the test, it was strongly magnetic. K has not only the enormously high tenacity of 157 tons per square inch, but is also accompanied by no less than 15 per cent. elongation. Apart from steel in the form of wire, probably no such high tensile strength had ever before been obtained. The tensile strength of K tested at normal temperature was 43·9 tons per square inch, with 55 per cent. elongation on 2 inches. These results show that in the future if such a material is required, then in some artificial manner it may be that this high tenacity will be obtained. The results are remarkable, seeing that the tensile strength of this alloy composed chiefly of the metal iron can be raised three times that of its original strength, or eight times that of iron.

This research was made several years ago, but at the time of the experiments it seemed to the author that if such tenacity could be produced artificially under the peculiar conditions in question, probably the results would be repeated later, in some of the many wonderful alloys of iron with other elements, which have been coming to the front of late years. In other words, it might be expected that sooner or later the artificial conditions produced on the materials described in the above experiment would be repeated in other alloys of iron still to be discovered, or in alloys which by certain heat treatment could be made to reach this particular physical condition and retain this high tenacity at ordinary temperatures. The term "extraordinary" is a word which can be justly used to describe these results, seeing that the metal iron in its pure state has a tenacity of only 18 to 21 tons per square inch.

As predicted, it has now been found that certain types of steel, chiefly those known as high-speed steels, can by heat treatment be made to possess very high tenacity. M. Pierre Breuil, in his

interesting report on "La Métallurgie à l'Exposition Universelle et Internationale de Bruxelles de 1910," showed that certain specimens of Holtzer steel exhibited gave in several instances a tensile strength of no less than 135 tons per square inch. It has been stated in Sheffield that it is now possible to obtain oil-hardened steel with a tensile strength of about 150 tons per square inch, such material having a tenacity in its normal condition of about 75 to 80 tons per square inch.

From the various foregoing results of the author's own iron-nickel alloys and those of the Holtzer type, it would appear that metallurgists are gradually working up to a point where it may be possible to obtain in bar and other forms the same high tenacity which is obtained in finely drawn piano-wire.

The interesting facts just mentioned are but another proof of how much there is still to be learnt in the manufacture and development of the qualities of special steels, and that qualities which at one time would have been regarded as impossible of attainment can be produced.

Value of Research Work.—The value of research work is now generally recognized. A large portion of the admirable Presidential Address delivered by Sir H. Frederick Donaldson, K.C.B., in April 1913 before this Institution was devoted to the consideration of this subject. It has been proposed to start a movement to co-ordinate research work so as to prevent the considerable amount of overlapping now existing. Whilst fully agreeing with this step, the author believes that co-ordination in research work should not be made to interfere in any way with individual research. Many works dealing with metallurgy and engineering in all its branches have fully equipped laboratories for carrying out experiments in connexion with their own manufacture, these experiments forming part, as it were, of their ordinary routine work, and they have always been found ready to make known many of the important results at which they have arrived. Metallurgists and engineers in this country cannot be taxed with working in secret; and whilst agreeing in the main, as stated above, with the movement which

Sir Frederick Donaldson would like to see initiated, individual effort, to the author's mind, should not and must not in the least be interfered with.

There is a rich and profitable field for the younger chemist if he will devote his attention to the particular branch of chemical research relating to the forms in which carbon is associated with iron in carbon alloys. In fact, to show the importance the author attaches to this subject, he has, through the medium of the two leading metallurgical Institutes in England and America, namely, the Iron and Steel Institute and the American Institute of Mining Engineers, offered in each country a prize of £200 for the best Paper or research on this subject—in other words, for continuing the investigations with regard to the combinations of iron and carbon, and thus follow up the great work originated by Abel, Müller, and Ledebur. This competition is not confined to any particular country, but is international and open to all. Amongst the subjects to be considered in this research would be a continuation of the researches referred to, and also those of Jullien, T. Sterry Hunt, Akerman, Arnold, E. D. Campbell, Harbord, Stead, Hogg, Parry, and others.

In a generic way, metallurgists now speak of carbides, sub-carbides, double carbides, special carbides, and other combinations. It is very desirable that those should be accurately defined and understood. It is also desirable to know whether there are other or new forms; if so, can these be separated and their characteristics obtained?

In addition to research work upon particular forms of carbide which have not yet been determined, it is also desirable and necessary to determine the state in which the carbon exists. For example, there exists what is termed a "missing form" of carbon, about which little is known or understood. More light is required about this form, as for many years very little has been added to our knowledge on this subject. It would be desirable, for example, to know whether the carbon not accounted for as carbide is "missed" in consequence of its being in so fine a state of division, or whether it is present in some special form or condition.

It may be mentioned as a general statement that when steel is in the austentic condition, it is softer then when transformed to the martensitic formation. In the former, the carbon is considered to be in complete solution ; yet steel showing martensitic structure is said to contain its carbon in complete solution also. If it could be shown that the martensitic formation results from the commencement in the falling out of solution of the carbon, this would be of great assistance to all those who are desirous of increased knowledge in this direction. It is therefore desirable to know exactly in what state the carbon exists in the austentic and martensitic formations.

It is also necessary, if possible, to ascertain the molecular constitution of the carbides. Such a point has been raised by the able American scientist Professor E. D. Campbell, and much important research work has been carried out by him with regard to certain particular combinations or forms of carbide. In other words, is the ordinary carbide Fe_3C ; Fe_6C_2, or is it some other combination ? If so, what is its nature and molecular constitution ? It may be mentioned that in order to facilitate the research, every reasonable assistance will be given by the Institutes concerned in making available the results of previous researches upon this and allied subjects ; in fact, a bibliography of the subject has been published in the *Bulletin* of the American Institute of Mining Engineers, and a copy will be furnished to those who expect to compete for the prize.

Let us remember that it is to the valuable properties of the many alloys of iron now made, from carbon steel to the complex alloy steel known as high-speed tool steel, which contains no less than five different elements apart from the iron itself, that is due the remarkable progress we have made, whether in the arts of peace or war. One simple concrete instance may be given—the modern motor vehicle, whether for private or trade use, with which such an enormous traffic is now carried on with so great convenience and comfort to the public of all lands. Take away the alloy steel used in its construction, and the motor vehicle could no longer be produced. The combination of lightness and strength necessary

in such modern products is only possible by the use of special alloy steels. To study the qualities of alloys of iron with other elements involves much research work, which, whilst it may not appear so attractive as the discovery, for example, of a new element, is none the less important.

Fortunately, there is no country where science and scientific work is more highly esteemed than in Great Britain. This is said advisedly, notwithstanding the jeremiads of many who ought to know better. It is often customary to say that we lack appreciation of scientific merit, but the author does not believe it. The fight for the cause of advance and progress may be severe, but in the end the English recognize the value of research to the full and true merit. We need not be ashamed when from this little island have come—not to mention those still with us—such men as Bacon, Newton, Priestley, Dalton, Boyle, Cavendish, Faraday, Davy, Joule, Huxley, Tyndall, Spencer, Darwin, Kelvin, and many others. On the more technical side, Dudley, Sturtevant, Pettus, Huntsman, Darby, Kirwin, Cort, Heath, George and Robert Stephenson, Heaton, Mushet, Whitworth, Bessemer, Siemens, Percy, Bell, Whitwell, Roberts-Austen, also many others in the Old World. In the New World, such men, as regards both classes of research, as Benjamin Franklin, Fulton, Agassiz, William Gibbs, Rowland, Barus, Edison, Bell, Steinmetz, Sterry Hunt, Howe, Holley, Fritz, and others.

The foregoing list is necessarily a very incomplete one and refers only to the workers in the Anglo-Saxon race. It, however, represents, at any rate, the names of some of those who have done the greatest work in the domains of the sciences of chemistry, physics, electricity, engineering, and metallurgy.

This Institution has always endeavoured to contribute to the increase in the general stock of human knowledge, and its very claim to existence is that we are all seeking to add to the comfort and further the progress of mankind. It is to the younger generation to carry on the noble traditions of the past, and to do all, severally and jointly, to shape, in the present while there is yet time, the destinies of the Future.

In conclusion, the author would like to return his best thanks to those who have helped him in the preparation of this Lecture, Messrs. Milne, Main, Elliot, Todd, and others, as well as to those who have lent some of the apparatus to add to his own collection of specimens.

The Lecture is illustrated by Plates 2 to 6 and 5 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

The Lecture was illustrated by the following exhibits:—

1. *Historical:—*

   Photographs of some early scientists, covering the period from 345 B.C. to A.D. 1882.

   Photographs of Sheffield in the years 1745 and 1819.

2. *Ancient Iron and Steel:—*

   Ancient iron specimens from the Colombo Museum, Ceylon: (*a*) Steel chisel from Sigiriya of the fifth century A.D., length 10 inches; (*b*) Ancient nail, probably from Sigiriya, and of same date as the chisel, length 13½ inches; (*c*) Native bill-hook or "ketta" from Dumbara, near Kandy.

   Photographs of ancient Sinhalese chisel, nail and bill-hook.

   Chippings and scale from the ancient wrought-iron pillar at Delhi. This pillar was probably made about fourth century A.D. It weighs 6 tons and is 24 feet in length. Photograph of Delhi Pillar.

   Indian carbon steel specimens from the Khan Baba Column, dating back to about 125 B.C. Photograph of Khan Baba Column.

3. *Books on Metallurgy:—*

   Old metallurgical books dating from 1505 A.D., selected from the lecturer's collection of over 200 volumes. Modern metallurgical books. Complete set of sixty-five research Papers on Metallurgy by the lecturer.

4. *Manganese Steel:—*

   Brittle manganese-steel poundings, 0·48 per cent. carbon, 4·80 per cent. manganese. Manganese-steel specimen, showing magnetic and non-magnetic properties on the same bar. Three small pieces of magnetic manganese steel, referred to in the Hadfield-Hopkinson research, which have been made magnetic by heat treatment. Manganese-steel rail bent double. Manganese-steel rail not bent.

Tensile bar of manganese steel before testing; after elongating 50 per cent.; after elongating 70 per cent.

Cast manganese-steel specimens, made by the lecturer in 1884 when discovering manganese steel. Small tough manganese-steel bars bent double. Manganese-steel rail rolled by Messrs. Schneider, Le Creusot, France. Drill used for drilling manganese steel. Drillings obtained from manganese-steel and ordinary steel rails after drilling for a definite length of time.

Large bar of "Resista" steel, bent double cold.

5. *Low-Hysteresis Steel*:—

First transformer made, in October 1903, of the author's low-hysteresis steel. Sheets of low-hysteresis steel as used in transformer.

6. *Tool Steel*:—

Tool as used twenty years ago. Original tool of the latest high-speed steel tested by Dr. J. O. Arnold, F.R.S. This tool removed 938 cubic inches of metal before being worn out. Wooden blocks representing the amount of material removed by each of the above tools in the same time.

7. *Alloys Generally*:—

Specimens of elements and alloys used in steel manufacture.

Small bars of embrittled steel, nicked and not nicked; also toughened steel, for comparison.

Ingot fractures: (*a*) aluminium steel; (*b*) silicon steel; (*c*) manganese steel.

Specimens of ductile tungsten and molybdenum.

Specimen of boron having glass-scratching hardness.

Weiss super-magnetic iron-cobalt alloy (33 per cent. cobalt).

Show-case of corrosion specimens.

Heusler alloy, 60 per cent. Cu, 25 per cent. Mn, 15 per cent. Al.

8. *Apparatus: Physical and Other*:—

Micro-telescope. This apparatus unites and concentrates the special features of the microscope and telescope in one instrument.

The Bonniksen dilatometer for measuring coefficient of expansion. This enables determinations to be made accurately on small samples over a wide range of temperature. By this means expansions as small as $\frac{1}{10000}$ on a length on $1\frac{1}{4}$ inch can be readily measured. This is an exceedingly delicate instrument.

Apparatus for determining calorific power of fuels.

9. *Apparatus: Microscopes and Microsections*:—

Mounted photomicrographs of typical structures.

Microscopes.

Microsections: (*a*) 0·4 carbon steel; (*b*) 0·9 carbon steel; (*c*) 1·2 carbon steel; (*d*) manganese steel, toughened; (*e*) manganese

steel, reheated to 550°, showing the magnetic network; (*f*) quenched steel, showing martensitic structure.

Law's autochrome photomicrographs.

10. *Apparatus for Determining Hardness:—*

Shore scleroscope.

Brinell ball-testing apparatus.

Specimens from lead to boron illustrating grades of hardness, varying from unity to about 700. Ball impressions (up to 700 ball hardness number) showing the difference in the size of the impression.

Specimen balls as used for testing apparatus.

11. *Projectiles:—*

Projectiles of various calibres, including those of 13·5-inch, 14-inch and 15-inch, after passing through hard-faced plates up to 16 inches in thickness.

12. *Caps:—*

Unfired cap of large calibre (14 inches). Ring from 14-inch cap, recovered after firing. The projectile struck with a velocity of about 1,560 feet per sec., and a total energy of 28,000 foot-tons. 4⅛-inch unfired cap. 4⅛-inch caps in ring form after being fired. Small cap sections. Unfired cap showing section. Photograph of small calibre fired cap ring. Photograph of cap ring, 4⅛-inch calibre, with fired and unfired 4⅛-inch projectiles at side.

13. *General:—*

Pig-iron from one of the earliest American blast-furnaces (A.D. 1734).

Alloy steels tested in liquid air. Dewar-Hadfield research.

Russian art work in steel.

Early crucible steel made by Huntsman more than 100 years ago.

Model of trawler wheelhouse. Illustrating experimentally the improved compass action due to the use of "non-magnetic steel."

Sound and unsound ingot sections.

Card of X-ray photographs of steel.

Photographs of various exhibits at the Hecla Works.

The Institution of Mechanical Engineers.

PROCEEDINGS.

MAY 1915.

An additional ORDINARY GENERAL MEETING was held at The Institution of Civil Engineers, London, on Friday, 14th May 1915, at Eight o'clock p.m.; Dr. W. CAWTHORNE UNWIN, F.R.S., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of new Members had been opened by a Committee appointed by the Council, and a certain number of candidates were found to be duly elected, but it was thought better that the names should not be read out on the present occasion, because it seemed a little unfair to make the new members subject to the payment of the subscription just before the long summer vacation, especially as no Summer Meeting was to be held. He therefore proposed that, although the gentlemen concerned be informed that they had been elected, the names should not be read out on the present occasion, but at the Meeting in October, when their subscriptions would begin.

The PRESIDENT announced that the following eleven Transferences had been made by the Council:—

Associate Members to Members.

ATKINSON, CHARLES ALFRED, . . .	London.
BONAR, JOHN, ...	Allahabad.
CALVERT, EDWARD, ...	London.
FLETCHER, WILLIAM MARSDEN, . .	Liverpool.
FOX, LEONARD MONRO, ...	London.
GIBB, NORMAN, ...	Bangkok.
GUEST, GEORGE NEVILL, ...	Birmingham.
MAWSON, ROBERT, ...	New York.
MITCHELL, WILLIAM GEORGE, . .	Kanchrapara.
ROSE, GEORGE FALCONER, . . .	Calcutta.
WADIA, ARDESHIR DOSÂBHAI, . .	Ahmedabad.

RESIGNATION OF TREASURER.

The PRESIDENT said he had to announce, to the regret of the Council, that the Treasurer of the Institution had found it necessary to resign his office. Mr. Huson had been Treasurer for the last seven years. He occupied a very responsible position; the funds of the Institution were in his hands, and the Members owed him a considerable debt of gratitude for the care which he had taken of the finances of the Institution. Mr. Huson's retirement from active life made it necessary for him to resign the Treasurership of the Institution, and he left them with their very sincere regret. As a small token of their appreciation of the services which he had rendered to the Institution and of his connexion with that body, the Council had decided to present Mr. Huson with a watch, which he now had the greatest pleasure in asking that gentleman to accept.

(The PRESIDENT then presented the watch to Mr. Huson.)

Mr. ARTHUR HUSON briefly thanked the President and the Members of the Institution for their very kind gift.

Appointment of Treasurer.

The President said it was now necessary to appoint a new Treasurer of the Institution, and it properly fell on his shoulders to move: "That, on the recommendation of the Council, Mr. F. H. Norwood, the successor to Mr. Huson as Manager of the Charing Cross Branch of the Union of London and Smiths Bank, be hereby appointed Honorary Treasurer of the Institution of Mechanical Engineers."

Professor A. J. Margetson seconded the Motion, which was carried unanimously.

Appointment of Auditor.

Mr. E. W. Petter said that the business of the late Mr. Robert A. McLean, who had audited the accounts of the Institution for the last 37 years, had been taken over by Messrs. Crane, Christmas and Co., and Mr. Raymond Crane, Fellow of the Institute of Chartered Accountants, had signified his willingness to undertake the duties of Auditor. He therefore moved: "That Mr. Raymond Crane, F.C.A., 46–47 London Wall, London, be appointed to audit the accounts of the Institution for the present year, at a remuneration of Fifty Guineas."

Mr. Sidney Sharp, in seconding the Motion, ventured to think that Mr. Raymond Crane would carry out the work of auditing the accounts in the same very satisfactory manner to the Institution that the late Mr. McLean had always shown.

The Resolution was put and carried unanimously.

The following Paper was read and discussed :—

"The Distribution of Heat in the Cylinder of a Gas-Engine"; by Professor A. H. GIBSON, D.Sc., *Member*, of University College, Dundee, and W. J. WALKER, B.Sc., of the Municipal School of Technology, Manchester.

The PRESIDENT, in moving that the thanks of the Institution be accorded to the Institution of Civil Engineers for allowing the Meeting to be held in their theatre, said that under pressure from Lord Moulton's Committee, which was doing work of the greatest urgency and importance in connexion with the War, the Council of the Institution had felt compelled to consent to their making use of their own Meeting Hall for designing and other purposes in connexion with their work. Being in that way turned out of their own home, they sought the hospitality of the Institution of Civil Engineers, and he accordingly moved that a Vote of Thanks be accorded to that Institution for lending them the use of their theatre on the present occasion.

The Resolution of Thanks was carried by acclamation.

The Meeting terminated at a Quarter past Nine o'clock. The attendance was 72 Members and 28 Visitors.

The Paper by Professor GIBSON and Mr. WALKER was read and further discussed at the Engineers' Club, Albert Square, Manchester, on Tuesday, 18th May 1915. Professor J. E. PETAVEL, F.R.S., *Member*, presided, and 48 Members and 29 Visitors were present.

THE DISTRIBUTION OF HEAT IN THE CYLINDER OF A GAS-ENGINE.

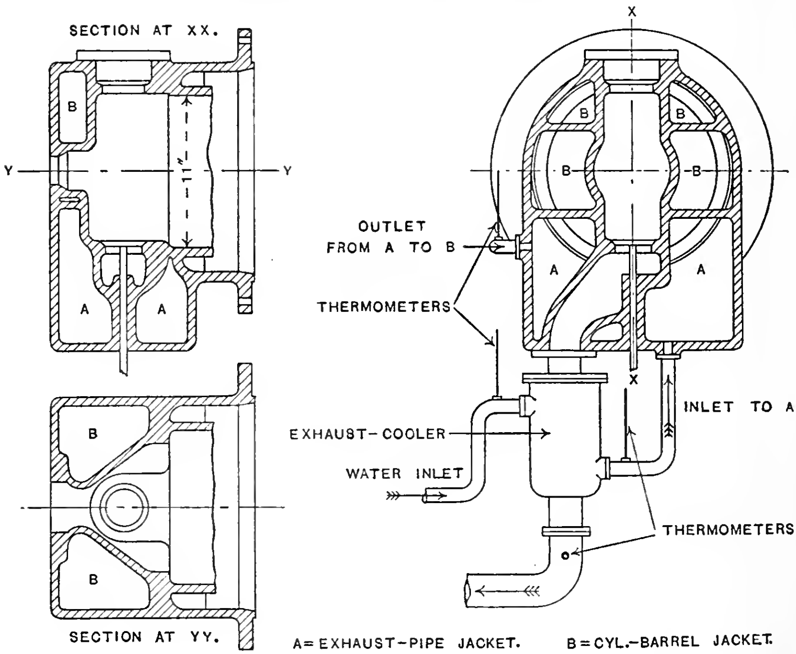
By Professor A. H. GIBSON, D.Sc., *Member*, of University College, Dundee, and W. J. WALKER, B.Sc. (*Carnegie Research Scholar*), of the Municipal School of Technology, Manchester.

The investigation outlined in this Paper is to some extent the outcome of a suggestion made by the British Association Committee for the investigation of Gaseous Explosions in their report for 1912. The report states (*inter alia*):—

. . . . "The effect of heat flow upon economy is not very marked, and it is therefore not surprising that no decisive verdict has yet been pronounced on the relation between economy and speed. There is no doubt that, given satisfactory ignition, economy is somewhat improved by increasing the speed, but the relation between speed and economy has not been so precisely determined as to permit a conclusion to be drawn about the part played by turbulence, nor, in view of the complication of the question, does it seem likely that much information can be derived from this source. A more promising line of inquiry would be a direct measurement of jacket losses at different speeds. The Committee are not aware that any accurate measurements of jacket loss at different speeds have ever been undertaken. From some rather rough measurements of this character, it appears that the heat loss per cycle does diminish with increase of speed, but not in proportion thereto."

An experimental gas-engine recently installed in the Engineering Laboratories at University College, Dundee, appeared to afford exceptional facilities for such an investigation. This engine, built by the National Gas Engine Co., Ltd., has a cylinder diameter of 11 inches and a stroke of 19 inches. The connecting-rod may be lengthened so as to vary the compression ratio between the limits

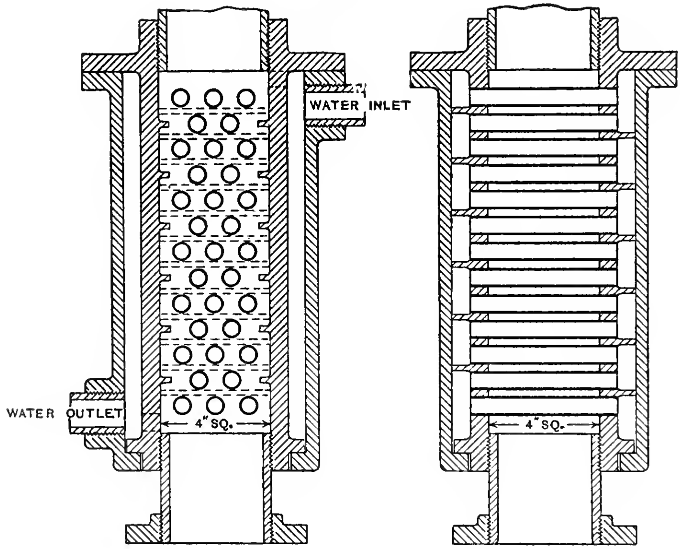
FIG. 1.—*General Arrangement of Jackets for Exhaust-Pipe and Cylinder, Exhaust-Cooler and Thermometers.*



5·17 and 6·62. Governing is on the hit-and-miss principle. A special feature of the engine consists in the arrangement of the cylinder-jackets, which were specially designed for experimental work. The jacket as usually constructed is here divided into two separate parts. One of these surrounds the exhaust-valve, and that portion of the exhaust passage included within the cylinder-casting, while the other covers the breech-end and barrel of the

cylinder. The jacket water is led in series through the two sections, its temperature being measured before and after passing through each of these. As is well known, the heat attributed to jacket losses in a gas-engine having the usual arrangement of jackets includes a certain proportion which, correctly, should be attributed to exhaust losses. In the engine under consideration, the magnitude of these two sources of loss can be ascertained with a much higher degree of accuracy. The arrangement of the

FIG. 2.—*Exhaust-Gas Cooler.*



jackets is indicated by the sectional drawing of the breech-end of the cylinder, shown in Fig. 1.

In order to measure the heat contained in the exhaust gases after leaving the cylinder, an exhaust-cooler, Fig. 2, was fitted to the exhaust branch. In this cooler the temperature of the gases is reduced by their passage over a series of 33 tubes, each $\frac{5}{8}$ inch outside diameter and 4 inches long. The jacket water passes through these tubes on its way to the cylinder jackets, and its temperature is measured before and after passing the cooler.

The trials, as finally carried out, were extended with a view to determine how the distribution of heat through the engine varies with—

(1) The speed of the engine.
(2) The brake horse-power.
(3) The compression ratio.
(4) The richness of the $\frac{\text{air}}{\text{gas}}$ mixture.

The normal speed of the engine is 200 revolutions per minute. In the trials, a range of speeds from 140 to 260 revolutions per minute was examined.

The maximum b.h.p. of the engine depends on the speed and mixture of air and gas. Its values are very approximately as follows:—

Ratio $\frac{\text{Air}}{\text{Gas}}$ (vols.).	Speed r.p.m.		
	150	200	250
7	25·0	31·5	36·0
9	20·0	25·0	28·5
11	16·5	20·5	23·5

In the trials the b.h.p. was varied from zero up to this full load capacity. Three different compression ratios were adopted. These are respectively 5·17, 5·70, and 6·62. Three different $\frac{\text{air}}{\text{gas}}$ mixtures were used. In round numbers these are 7 : 1, 9 : 1, and 11 : 1. In individual trials of the same series the richness of the mixture varied by not more than 5 per cent. on each side of the mean. In the great majority of cases the variation did not exceed 2 per cent. on each side of the mean.

In all some 130 trials were carried out.

Experimental Measurements.—The methods adopted in measuring and calculating the various heat quantities involved, agree in

principle with those outlined in the Inst. C.E. report on Internal-Combustion Engines.*

Gas Supply.—Town gas was used in the engine. An average analysis of this gave the following result:—

CO_2	3·8 per cent.
O_2	1·1 "
CO	13·0 "
CH_4	26·3 "
C_2H_4	4·7 "
H	38·0 "
N	13·1 "

The corresponding lower calorific value (calculated) at standard temperature and pressure is 521·4 B.Th.U. per cubic foot. The gas supply is measured by a dry meter, which was calibrated before the trials against a standard gasometer. The calorific values, higher and lower, were measured by a Boys' calorimeter deriving its supply from the gas-main. The calorimeter was in operation during the whole duration of each trial, and the mean calorific value adopted for each trial is the mean of the results obtained from the calorimeter during this period. The mean of the lower and higher values obtained during the trials were respectively 520 B.Th.U. and 577 B.Th.U. per cubic foot. The lower value has been used in all calculations.

Air Supply.—This is drawn through two 1,500-light dry meters in parallel. These meters were calibrated against a standard gasometer.

Measurement of Work.—The brake horse-power is measured by a water-cooled Prony brake whose drum is mounted alongside the fly-wheel. The indicated horse-power is deduced from diagrams taken with a Dobbie-McInnes gas-engine indicator. A $\frac{1}{350}$ spring was used for the power diagrams, and a $\frac{1}{16}$ spring for diagrams

* Proceedings, Inst. C.E., 1906, vol. clxiii, page 241.

intended for the measurement of suction pressures. While no high degree of accuracy is to be anticipated for these measurements of indicated work, they appear to be very consistent.

Jacket Water.—As already stated, the jacket water passes first through the exhaust-gas cooler, then through the jacket surrounding the exhaust valve and exhaust passage and finally through the barrel and breech jacket. On leaving the latter jacket it is measured in one of a pair of calibrated measuring tanks. Temperatures are measured before and after each jacket or section of a jacket, and from a knowledge of the weight of water passing, the heat flow through the walls of each stage is readily computed. The weight of water in each trial was adjusted so as to give a final temperature as near as possible to 145° F. (63° C). In some trials when the temperature had become steady, this final temperature was two or three degrees above or below 145° F. Sensibly, however, the final temperature was constant over the whole series of trials.

Thermometers.—All thermometers were calibrated before the trials.

Heat in Exhaust Gases.—Systematic analyses of the exhaust gases were carried out, mainly with a view to ensuring that combustion was complete before the end of expansion. In no case was more than a trace of combustible found in the gas. In the great majority of cases no such trace was found.

Of the total heat in the exhaust gases leaving the cylinder, part is absorbed by the water in the exhaust-valve jacket, and part in the exhaust-gas cooler. The cooler is not sufficiently large to cool down the gases to atmospheric temperature, and their temperature on leaving the cooler is usually between 200° and 300° F. The heat carried away by these gases is estimated from a knowledge of their weight, specific heat, and temperature. Their weight is known, since it is equal to the weight of air + gas + moisture entering the cylinder. The amount of steam formed during combustion is known from the records of the gas-calorimeter,

while the specific heat of the dry exhaust gas, which varies a little with its composition, is sensibly equal to 0·24. The mean temperature is measured by means of a mercury thermometer.

Method of Conducting Trials.—Having started up the engine, the governor is adjusted to give the desired speed, and, by reference to the air and gas meters, the air and gas inlet-valves are adjusted until the required air-gas mixture is attained. The necessary brake load is then applied; the ignition is advanced or retarded until a satisfactory diagram with a vertical explosion line is obtained; and the jacket water is regulated so as to give the required outlet temperature. When all conditions are steady, the trial commences. Each trial extended over some 30 to 45 minutes.

Experimental Data and Results.—In view of the very large number of trials involved, it has been thought inadvisable to attempt to give the detailed observations and deductions in this Paper. From the experimental results, a heat balance-sheet has been drawn up for each trial. From the data thus obtained, a series of curves has been plotted, and by interpolation from these curves the more important data corresponding to speeds of 150, 200, and 250 revolutions per minute, and to brake horse-powers of 10, 15, 20, 25 and 30, have been deduced for each gas mixture and for each compression. These are given in Tables 1 to 5 (pages 381–385), while the salient features are shown graphically in the curves of Figs. 3 to 6 (pages 370–373).

The main results of the investigation may be summarized as follows:—

Mechanical Efficiency.—The mechanical efficiency of the engine—

(1) Increases with increasing loads.

(2) Diminishes as the ratio $\frac{\text{air}}{\text{gas}}$ increases. (Fig. 4.)

(3) Diminishes as the speed increases. (Fig. 5.)

(4) Is sensibly independent of the compression ratio. (Fig. 6.)

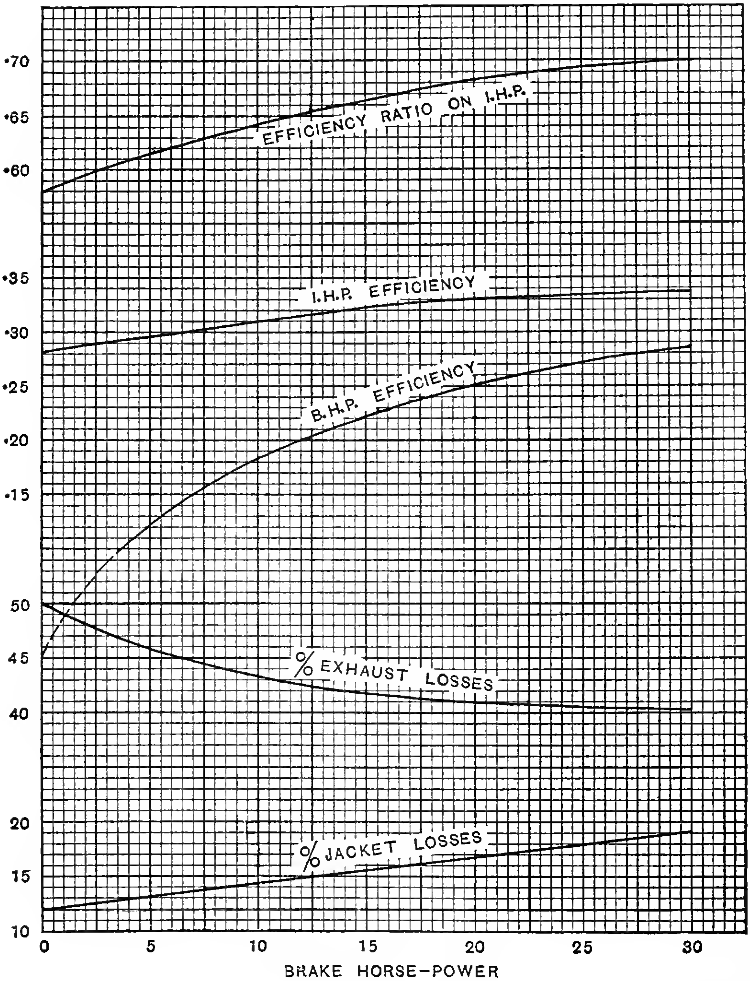
The maximum efficiency attained in these trials, i.e., at full load with the richest (7 : 1) mixture, and at the lowest speed (150

(*Continued on page* 374.)

Fig. 3.

Compression Ratio = 5·17

R.P.M. = 200 Air : Gas = 9 : 1



Note.—" Efficiency Ratio " shown at the top of Figs. 3, 4, 5, and 6, would be better substituted by "Relative Efficiency," according to the suggestion made by Captain Sankey on page 394.

Fig. 4.

Full Load. Compression Ratio = 5·17

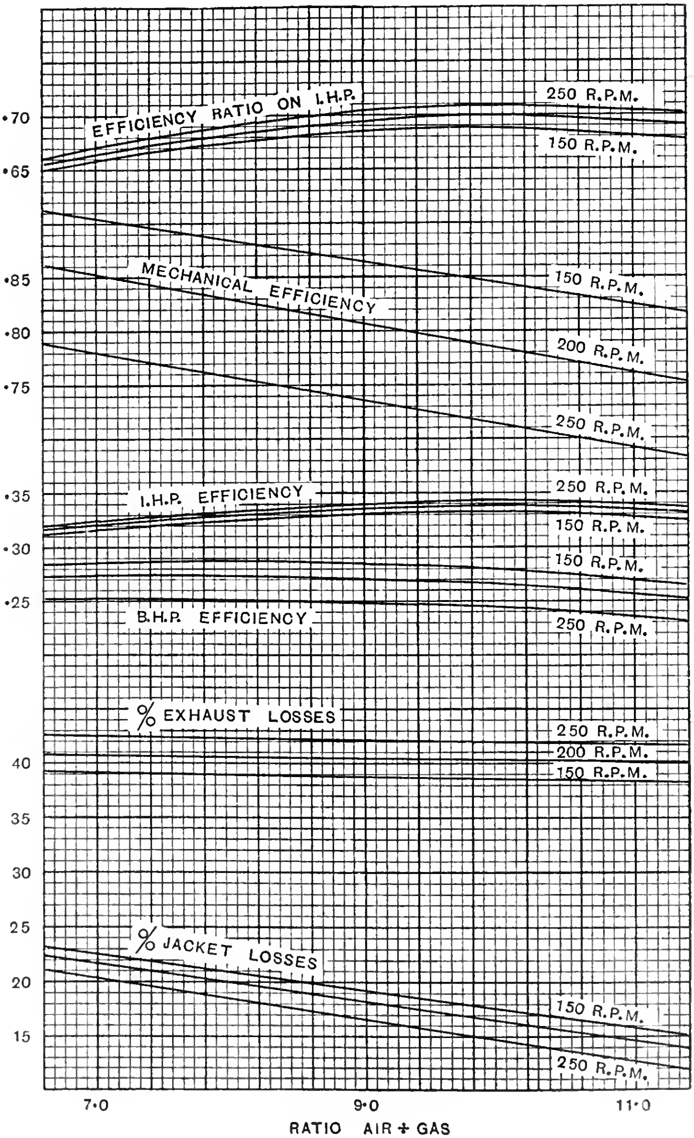


Fig. 5.

Compression Ratio = 5·17 Air : Gas = 9 : 1

Curves AA are from tests at full load.
" BB " " " " 0·8 per cent. full load.
" CC " " " " 0·6 " " " "

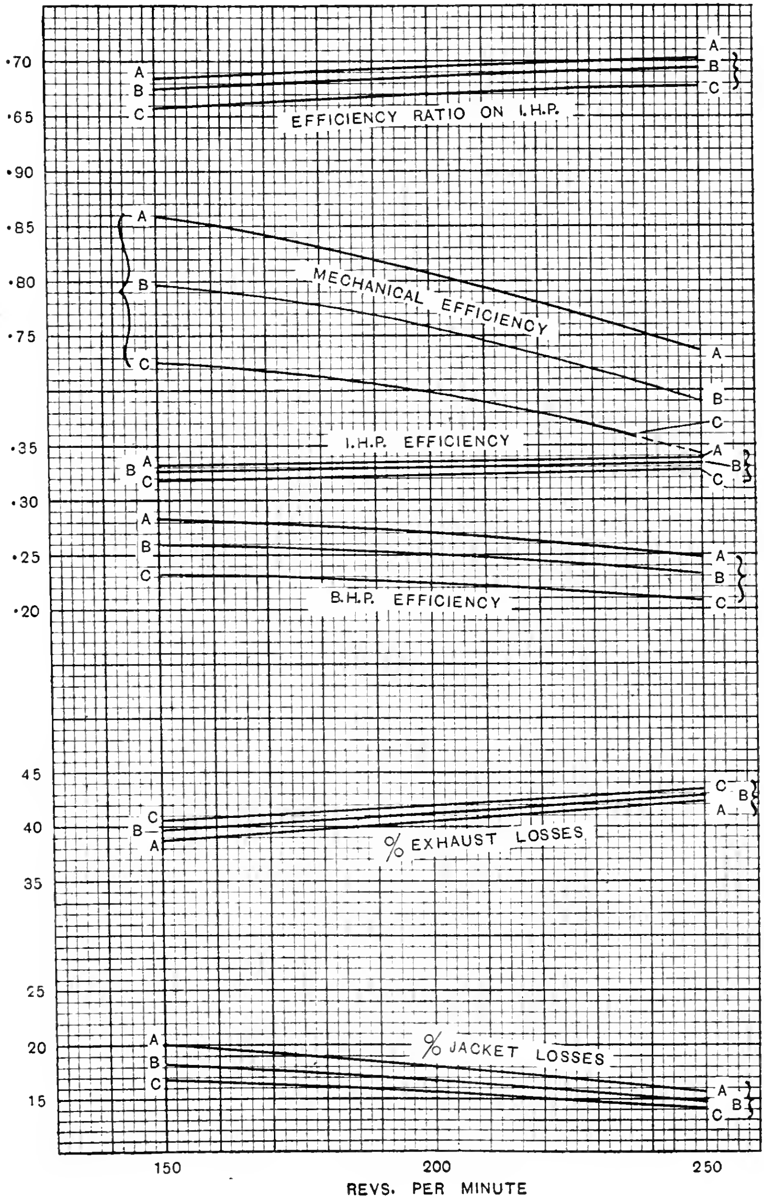
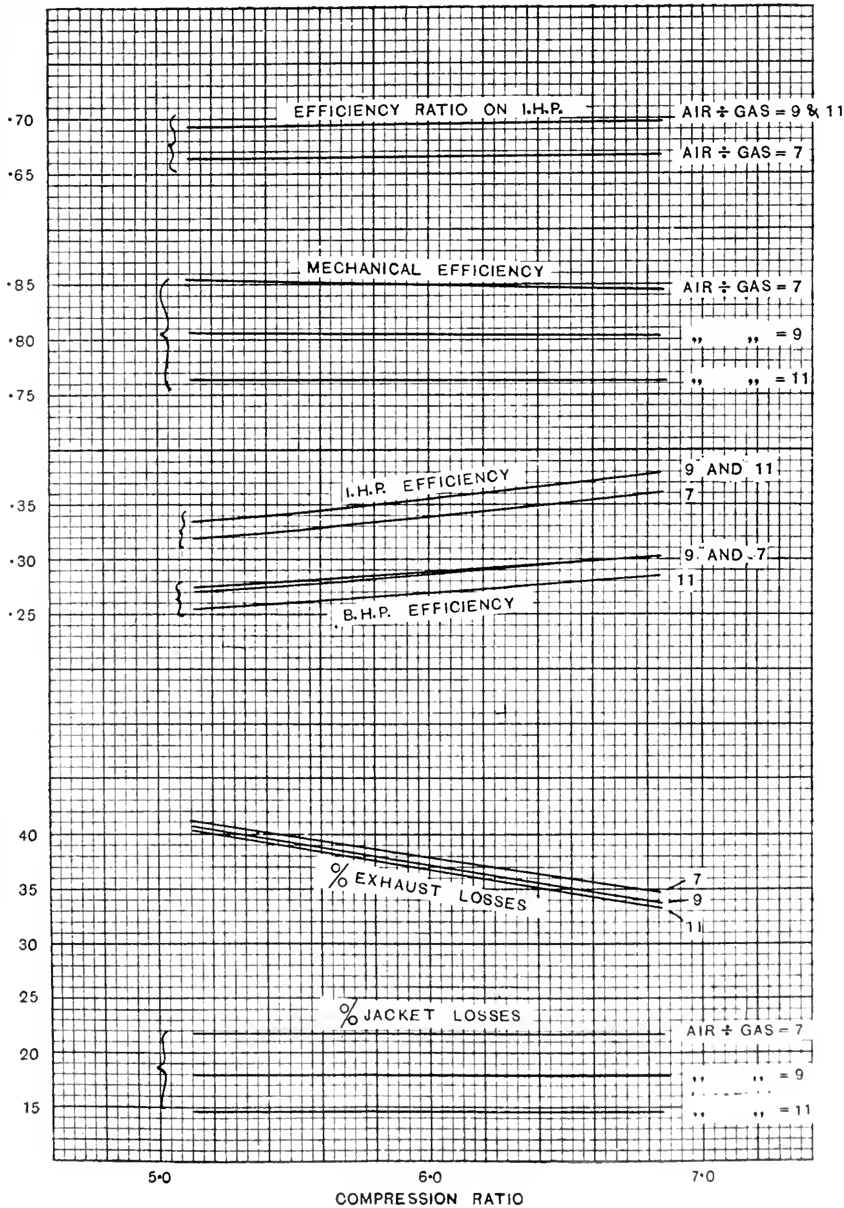


Fig. 6.—Full Load. 200 revolutions per minute.



revolutions per minute) is 88 per cent. At the normal speed of 200 revolutions per minute and with the same mixture, the efficiency is 85 per cent., while with this same speed and the weakest (11 : 1) mixture, it falls to 76·7 per cent.

Thermal Efficiency on I.H.P.—The thermal efficiency as measured on the i.h.p.—

(1) Increases with the load. (Fig. 3.)

(2) Attains a maximum with an $\frac{\text{air}}{\text{gas}}$ mixture of approximately 10 : 1. (Fig. 4.)

(3) Increases very slightly as the speed increases. (Fig. 5.)

(4) Increases as the compression ratio increases. (Fig. 6.)

The maximum percentage thermal efficiencies attained are as follows :—

Compression Ratio.		5·17	5·70	6·62
Speed	150	33·1	34·4	36·5
	200	33·9	35·3	37·4
	250	34·4	35·8	37·9

Thermal Efficiency on B.H.P.—As measured on the b.h.p., the thermal efficiency—

(1) Increases with the load. (Fig. 3.)

(2) Attains a maximum with an $\frac{\text{air}}{\text{gas}}$ ratio of 8 : 1, i.e. with a richer mixture than gives maximum i.h.p. efficiency. (Fig. 4.)

(3) Diminishes as speed increases. (Fig. 5.)

(4) Increases with the compression ratio. (Fig. 6.)

The maximum percentage-efficiencies on the b.h.p. are as follows :—

Compression Ratio.		5·17	5·70	6·62
Speed	150	27·9	29·1	31·0
	200	27·5	28·6	30·2
	250	25·7	26·7	28·3

Efficiency Ratio.—Adopting the air cycle as the standard of comparison, the ideal efficiencies corresponding to the various compression ratios are :—

Compression ratio . .	5·17	5·70	6·62
Air-cycle efficiency . .	0·482	0·501	0·532

The ratio of the actual thermal efficiency, measured on the i.h.p., to the corresponding air-cycle efficiency—

(1) Increases with the load. (Fig. 3.)

(2) Has a maximum value when the ratio $\frac{\text{air}}{\text{gas}}$ is approximately 10 : 1. (Fig. 4.)

(3) Increases slightly with speed. (Fig. 5.)

(4) Is sensibly independent of the compression ratio. (Fig. 6.)

At full load, and with the most efficient air-gas mixture, the relative efficiencies are, for all compressions :—

Revolutions . . .	150	200	250
Efficiency ratio . .	0·687	0·700	0·709

Exhaust-Losses.—The percentage exhaust-losses—

(1) Diminish as the load increases. (Fig. 3.)

(2) Diminish very slightly as the ratio $\frac{\text{air}}{\text{gas}}$ increases. (Fig. 4.)

(3) Increase as the speed increases. (Fig. 5.)

(4) Diminish as the compression ratio increases. (Fig. 6.)

At full load the exhaust-losses in these trials lie between the limits 33·6 per cent. and 42·5 per cent. The former value corresponds to a weak mixture, high compression, and low speed, and the latter to a rich mixture, low compression ratio, and high speed.

Jacket-Losses.—The percentage heat carried away by the water flowing through the cylinder jackets—not including the exhaust-valve jacket—

(1) Increases with the load. (Fig. 3.)

(2) Diminishes as the ratio $\frac{\text{air}}{\text{gas}}$ increases. (Fig. 4.)

(3) Diminishes as the speed increases. (Fig. 5.)

(4) Is sensibly independent of the compression-ratio. (Fig. 6.)

With the strongest mixture, and at full load, the percentage heat transmitted to these jackets is 1·10 times as great at 150 revolutions per minute as at 250 revolutions per minute, while with the weakest mixture the ratio becomes 1·23. Since at 150 revolutions per minute the period of contact per cycle, of hot gases and cylinder walls, is 1·66 times as great as at 250 revolutions per minute, the rate of transmission of heat through the cooling surfaces is evidently much greater at the highest speed. An examination of the indicator diagrams, moreover, shows that the maximum pressure and temperature attained in the cylinder is approximately 6 per cent. greater at 150 than at 250 revolutions per minute, so that this increased rate of transmission is obtained in spite of a lower gas temperature. The reason is apparently to be found in the fact that the greater turbulence of the working fluid at the higher rates of speed increases its effective conductivity to an extent which more than counterbalances the effects of a smaller temperature difference and a shortened time of contact. Other things being equal, a 6 per cent. increase in the temperature of the gases would probably increase the heat transmitted by conduction and radiation by some 15 per cent., so that it may be taken approximately that the effective conductivity is increased in the same ratio as the speed of the engine.

Radiation-Losses.—The radiation-loss—that is, the balance of the heat accounted for as indicated work, in the exhaust and in the jacket water—

(1) Diminishes as the load increases. (Table 3, page 383.)

(2) Increases as the ratio $\frac{\text{air}}{\text{gas}}$ increases. (Table 3.)

(3) Diminishes as the speed increases. (Table 3.)

(4) Increases slightly as the compression-ratio increases. (Table 3.)

At full load, radiation accounts for between 5 per cent. and 14 per cent. of the heat given to the engine, the former value obtaining with a rich mixture, high speed, and low compression-ratio, and the latter with a weak mixture, low speed, and high compression-ratio. Its variation with load is indicated in the following Table:—

Compression-Ratio $5 \cdot 17$; $\frac{\text{air}}{\text{gas}} = 9$				
Brake Load.		Zero.	Half Load.	Full Load.
		Per cent.	Per cent.	Per cent.
Revs.	150	13·8	12·2	8·9
	200	11·9	10·6	8·0
	250	10·9	9·8	7·5

Distribution of Heat up to end of Expansion Stroke.—Since part of the heat carried away by the jacket water passes into the cylinder walls after release, this should, in a true heat-balance, be credited to exhaust. The item attributed to radiation represents heat lost by radiation from the hot exposed surfaces of the piston and of the unjacketed portion of the breech, and from the outer surface of the jackets. Although this loss is wholly due to heat flow through the walls, only part of this flow takes place during the expansion stroke. The remainder, occurring after the end of this stroke, is also to be attributed to the exhaust.

Thus in a heat-balance drawn for the working fluid up to the end of expansion, the apparent heat flow into the walls is to be increased by the greater part of this radiation-loss, and to be diminished by that part of the heat transmitted to the jacket water during exhaust. Similarly the apparent exhaust-losses are to be increased by some small portion of the radiation-loss and by that part of the heat given to the jacket water during exhaust. The net result is that both the wall-losses and the exhaust-losses as given

by direct measurement are to be increased by some unknown proportion of the radiation-loss.

A true heat-balance for this portion of the cycle can only be deduced if the heat given per cycle in the combustible gas, the work done per cycle, and the energy of the working fluid at the end of expansion, are known. In order to determine the energy at the end of expansion, it is necessary to know:—

(1) The temperature at the end of expansion.

(2) The quantity of the working fluid in the cylinder.

(3) Its internal energy per cubic foot in terms of its temperature.

In these trials all the data necessary for determining items (1) and (2) are available. The temperatures at the end of expansion have been deduced from a knowledge of the temperatures at the beginning of compression and of the pressures at the end of expansion and at the beginning of compression, while the temperatures at the beginning of compression have been calculated by the method outlined by Dugald Clerk.* The internal energy per cubic foot corresponding to the various release temperatures has been deduced from curves given by Hopkinson.† The mean results of these calculations, carried out for a number of the trials, are embodied in the heat-balances given in Table 5 (page 385). Since their accuracy depends on that of the indicator diagrams, the possibility of error in these should not be overlooked. It is unlikely, however, that the error in any item of these balance-sheets exceeds about 1 per cent., while it may be much less.

The results indicate in general, that of the total radiation-loss obtained by difference from the heat measurements, a proportion ranging from about 0·33 to 0·40 is to be added to the apparent exhaust-losses, the remainder going to increase the apparent jacket or wall losses. This proportion attains its highest value with the highest compression-ratios and with the richest mixtures.

A comparison of these with results obtained in a similar

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* Proceedings, Inst. C.E., 1907, vol. clxix, page 148.

† Proceedings, I.Mech.E., 1908, page 424.

manner by Hopkinson * on a slightly larger engine shows a fairly close agreement. In round numbers the figures are as follows. Those attributed to the authors are obtained by interpolation from the figures of Table 5.

—	$\frac{\text{Air}}{\text{Gas}} = 10\cdot8$		$\frac{\text{Air}}{\text{Gas}} = 8\cdot1$	
	Hopkinson.	Authors.	Hopkinson.	Authors.
Heat as i.h.p. . .	37	36	33	35
Heat in exhaust . .	42	41	39	39
Heat flow to walls . .	21	23	28	26

The engine used by Hopkinson had a cylinder diameter = 11·5 inches; stroke = 21 inches; compression-ratio = 6·37; revolutions = 110 per minute.

Heat entering Exhaust-valve Jacket.—The percentage heat entering the exhaust-valve jacket is shown in Table 3 (page 383). From these figures it appears that its value ranges from 8·0 to 12·5 per cent., being greatest at low loads, low speeds, and with low compression-ratios and rich mixtures. At full load it varies as shown in the following Table:—

—		Compression-Ratio.								
		5·17			5·70			6·62		
$\frac{\text{Air}}{\text{Gas}}$		7	9	11	7	9	11	7	9	11
Revs.	150 .	11·1	10·7	10·3	10·5	10·1	9·7	9·7	9·3	9·1
	200 .	10·4	10·9	9·7	10·0	9·6	9·3	9·4	8·9	8·7
	250 .	9·8	9·5	8·9	9·4	9·1	8·5	9·0	8·4	8·0

* Proceedings, I.Mech.E., 1908, page 417.

If this be added to the jacket-loss given in Table 4 (page 384), it gives the jacket-loss as determined from trials of an engine fitted with the usual arrangement of jackets. It is interesting to note in this connexion, that with weak mixtures and fairly high compression-ratios, the jacket-losses obtained in this way are in substantial agreement with those obtained by analysis as giving the heat flow during expansion. For example, at full load, with $\frac{\text{air}}{\text{gas}}$ mixture 11 : 1 and with compression-ratio 6·62, the percentage wall-losses by analysis at speeds of 150, 200, and 250 revolutions per minute are respectively 24·6, 23·3, and 21·3, Table 5 (page 385), while the percentages of heat to barrel and valve jackets are respectively 24·9, 23·5, and 20·9. Under favourable circumstances it appears that a heat balance-sheet obtained by measuring the indicated work and jacket heat of a commercial type of engine, and by estimating exhaust-losses by difference, is in extremely close agreement with the balance-sheet based on the internal energy of the gas at the end of expansion. For fairly rich mixtures and lower compression-ratios the measured jacket-losses are, however, always in excess of those more correctly computed from the internal energy of the gas.

The authors would express their sense of indebtedness to the Trustees of the Carnegie Research Fund, whose scholarship to Mr. Walker rendered possible his co-operation in the work. Also to Mr. Linton, of the Engineering Staff of University College, for much assistance given during the trials.

The Paper is illustrated by 6 Figs. in the letterpress.

TABLE 1.

Thermal Efficiencies: (a) on I.H.P., and (b) on B.H.P.

—			Compression-Ratio.								
			5·17			5·70			6·62		
Ratio Air/Gas			7	9	11	7	9	11	7	9	11
B.h.p.	Speed r.p.m.										
10	150	a	29·1	30·8	31·6	30·3	32·4	32·9	32·2	34·4	35·0
		b	19·8	21·2	21·6	20·6	22·0	22·3	21·8	23·4	23·8
	200	a	29·5	31·2	32·0	30·7	32·8	33·3	32·6	34·8	35·4
		b	17·2	18·4	18·8	17·9	19·1	19·5	19·0	20·2	20·6
	250	a	29·9	31·6	32·4	31·1	33·2	33·7	33·0	35·2	35·8
		b	14·4	15·5	15·8	15·0	16·0	16·4	15·9	17·0	17·4
15	150	a	30·2	31·9	32·4	31·5	33·2	33·7	33·5	35·3	35·8
		b	23·3	24·7	25·2	24·2	25·7	26·2	25·6	27·2	27·8
	200	a	30·6	32·3	32·8	31·9	33·6	34·1	33·9	35·7	36·2
		b	21·1	22·2	22·6	21·9	23·1	23·5	23·2	24·4	24·9
	250	a	30·9	32·6	33·1	32·2	33·9	34·4	34·2	36·0	36·5
		b	18·3	19·3	19·6	19·0	20·0	20·3	20·1	21·2	21·6
20	150	a	30·9	32·8	—	32·3	34·1	—	34·3	36·2	—
		b	26·0	27·6	—	27·0	28·6	—	28·6	30·1	—
	200	a	31·2	33·0	33·5	32·6	34·3	34·8	34·6	36·4	37·0
		b	23·6	25·0	25·5	24·6	26·0	26·5	26·1	27·6	28·1
	250	a	31·5	33·3	33·8	32·9	34·6	35·1	34·9	36·7	37·3
		b	20·5	22·2	22·6	21·8	23·0	23·4	22·6	24·4	24·8
25	150	a	31·4	—	—	32·7	—	—	34·8	—	—
		b	27·4	—	—	28·8	—	—	30·5	—	—
	200	a	31·7	33·5	—	33·0	34·9	—	35·1	37·1	—
		b	25·5	27·0	—	26·5	28·0	—	28·1	29·9	—
	250	a	31·9	33·7	34·2	33·2	35·1	35·6	35·3	37·3	37·8
		b	22·7	24·1	25·0	23·6	25·0	26·0	25·0	26·4	27·2
30	150	a	—	—	—	—	—	—	—	—	—
		b	—	—	—	—	—	—	—	—	—
	200	a	32·1	—	—	33·4	—	—	35·4	—	—
		b	27·2	—	—	28·3	—	—	29·8	—	—
	250	a	32·3	34·1	—	33·6	35·5	—	35·6	37·7	—
		b	24·5	25·5	—	25·4	26·5	—	26·8	28·0	—

TABLE 2.—(*a*) *Heat in Exhaust;* (*b*) *Heat transferred to Barrel Jacket-water; expressed as a percentage of the total Heat Supply.*

Jacket-losses are sensibly independent of the compression-ratio.

—			Compression-Ratio.								
			5·17			5·70			6·62		
Ratio $\frac{\text{Air}}{\text{Gas}}$			7	9	11	7	9	11	7	9	11
B.h.p.	Speed r.p.m.										
10	150	*a*	42·1	41·0	40·3	39·9	38·4	37·8	36·2	35·2	34·3
		b	17·0	16·0	14·1	17·4	16·0	14·1	17·0	16·0	14·1
	200	*a*	44·1	43·2	42·3	41·4	40·7	39·8	38·1	37·3	36·4
		b	16·0	14·3	12·2	16·3	14·3	12·2	16·3	14·3	12·2
	250	*a*	46·1	45·4	44·4	43·4	42·7	41·9	40·0	39·3	38·5
		b	15·0	12·6	10·3	15·3	12·6	10·3	15·3	12·6	10·3
15	150	*a*	40·8	39·7	39·1	38·5	37·7	36·8	35·2	34·8	33·8
		b	18·6	17·6	15·5	—	—	—	—	—	—
	200	*a*	42·7	41·8	41·0	40·3	39·6	38·7	36·9	36·3	35·5
		b	17·4	15·6	13·4	—	—	—	—	—	—
	250	*a*	44·6	43·9	43·1	42·2	41·5	40·7	38·6	37·9	37·1
		b	16·1	13·7	11·3	—	—	—	—	—	—
20	150	*a*	39·9	39·1	—	37·8	37·0	—	34·5	33·7	—
		b	20·3	19·2	—	—	—	—	—	—	—
	200	*a*	41·8	41·1	40·1	39·5	38·8	37·9	36·0	35·3	34·3
		b	18·8	16·8	14·6	—	—	—	—	—	—
	250	*a*	43·7	43·0	42·2	41·3	40·6	39·8	37·5	36·8	36·0
		b	17·2	14·5	12·3	—	—	—	—	—	—
25	150	*a*	39·3	—	—	37·3	—	—	34·2	—	—
		b	22·2	—	—	—	—	—	—	—	—
	200	*a*	41·2	40·5	—	39·2	38·4	—	35·6	34·9	—
		b	20·2	18·0	—	—	—	—	—	—	—
	250	*a*	43·1	42·4	41·6	41·0	40·3	39·5	37·0	36·3	35·5
		b	18·3	15·3	13·3	—	—	—	—	—	—
30	150	*a*	—	—	—	—	—	—	—	—	—
		b	—	—	—	—	—	—	—	—	—
	200	*a*	40·8	—	—	39·0	—	—	35·4	—	—
		b	21·6	—	—	—	—	—	—	—	—
	250	*a*	42·7	41·9	—	40·8	40·1	—	36·8	36·1	—
		b	19·5	16·1	—	—	—	—	—	—	—

TABLE 3.

Radiation-Loss (by difference); (b) Heat to Exhaust-valve jacket; expressed as a percentage of the total Heat Supply.

—			Compression-Ratio.								
			5·17			5·70			6·62		
Ratio $\frac{\text{Air}}{\text{Gas}}$			7	9	11	7	9	11	7	9	11
B.h.p.	Speed r.p.m.										
10	150	a	11·8	12·2	14·0	12·8	13·2	15·2	14·2	14·4	16·2
		b	12·5	11·4	10·8	11·5	10·8	10·4	10·2	10·0	9·9
	200	a	10·4	11·3	13·5	11·6	12·2	14·7	13·3	13·6	16·0
		b	11·2	10·4	9·9	10·6	10·0	9·6	9·8	9·4	9·2
	250	a	9·0	10·4	12·9	10·2	11·5	14·1	12·0	12·9	15·4
		b	10·4	9·8	9·1	10·0	9·5	8·9	9·5	8·9	8·6
15	150	a	10·4	10·8	13·0	11·4	11·7	14·0	12·7	12·3	14·8
		b	11·8	11·0	10·5	11·0	10·4	10·0	10·0	9·6	9·4
	200	a	9·3	10·3	12·8	10·4	11·2	13·8	11·8	12·4	14·9
		b	10·8	10·2	9·8	10·3	9·8	9·4	9·6	9·1	8·8
	250	a	8·4	9·8	12·5	9·5	10·9	13·6	11·1	12·4	15·1
		b	10·2	9·7	9·0	9·8	9·3	8·7	9·2	8·6	8·2
20	150	a	8·9	9·0	—	9·6	9·8	—	10·9	11·0	—
		b	11·4	10·7	—	10·7	10·1	—	9·9	9·3	—
	200	a	8·2	9·1	11·8	9·1	10·1	12·7	10·6	11·5	14·0
		b	10·5	10·0	9·7	10·1	9·7	9·3	9·5	9·0	8·7
	250	a	7·6	9·2	11·8	8·6	10·3	12·8	10·4	12·0	14·4
		b	10·0	9·6	8·9	9·6	9·2	8·5	9·1	8·5	8·0
25	150	a	7·1	—	—	7·8	—	—	8·8	—	—
		b	11·2	—	—	10·6	—	—	9·8	—	—
	200	a	6·9	8·0	—	7·6	8·7	—	9·1	10·0	—
		b	10·4	9·9	—	10·0	9·6	—	9·4	8·9	—
	250	a	6·7	8·6	9·9	7·5	9·3	11·6	9·4	11·1	13·4
		b	10·0	9·6	8·9	9·6	9·1	8·5	9·0	8·3	7·9
30	150	a	—	—	—	—	—	—	—	—	—
		b	—	—	—	—	—	—	—	—	—
	200	a	5·5	—	—	6·0	—	—	7·6	—	—
		b	10·4	—	—	10·0	—	—	9·4	—	—
	250	a	5·5	7·9	—	6·1	8·3	—	8·1	10·1	—
		b	9·9	9·5	—	9·5	9·0	—	9·0	8·2	—

TABLE 4.

Heat Balance at Full Load—i.e., with one Explosion per Cycle.

Air/Gas	Compression-Ratio.	Speed r.p.m.	Percentage of Heat Distribution. Heat as i.h.p.	Exhaust.	Jacket.	Radiation.	Efficiency Ratio on B.h.p.	I.h.p.	Heat as b.h.p.
7	5·17	150	31·5	39·2	22·4	6·9	0·575	0·654	27·7
		200	32·2	40·7	21·7	5·4	0·569	0·668	27·4
		250	32·6	42·5	20·2	4·7	0·531	0·676	25·6
	5·70	150	32·8	37·2	22·4	7·6	0·578	0·654	29·0
		200	33·5	38·9	21·7	5·9	0·568	0·667	28·5
		250	33·8	40·6	20·2	5·4	0·529	0·674	26·5
	6·62	150	34·9	34·1	22·4	8·6	0·579	0·656	30·8
		200	35·5	35·3	21·7	7·5	0·565	0·668	30·0
		250	35·8	36·7	20·2	7·3	0·530	0·673	28·2
9	5·17	150	32·8	39·1	19·2	8·9	0·572	0·680	27·6
		200	33·5	40·5	18·0	8·0	0·560	0·695	27·0
		250	34·0	42·0	16·5	7·5	0·521	0·705	25·1
	5·70	150	34·1	37·0	19·2	9·7	0·570	0·679	28·6
		200	34·9	38·4	18·0	8·7	0·560	0·695	28·1
		250	35·4	40·3	16·5	7·8	0·522	0·705	26·2
	6·62	150	36·2	33·7	19·2	10·9	0·568	0·681	30·2
		200	37·1	34·9	18·0	10·0	0·561	0·697	29·8
		250	37·6	36·3	16·5	9·6	0·520	0·707	27·6
11	5·17	150	32·8	38·9	15·8	12·5	0·540	0·680	26·0
		200	33·5	40·0	14·8	11·7	0·534	0·695	25·7
		250	33·9	41·8	12·9	11·4	0·502	0·704	24·2
	5·70	150	34·1	36·5	15·8	13·6	0·538	0·680	27·0
		200	34·9	37·8	14·8	12·5	0·532	0·695	26·7
		250	35·4	39·6	12·9	12·1	0·502	0·705	25·2
	6·62	150	36·2	33·6	15·8	14·4	0·540	0·680	28·8
		200	37·1	34·2	14·8	13·9	0·532	0·697	28·3
		250	37·6	35·8	12·9	13·7	0·500	0·707	26·6

TABLE 5

Heat Balance at end of Expansion Stroke.

Full Load.

Air/Gas	Compression-Ratio.	Speed r.p.m.	Percentage Heat Distribution. Heat as i.h.p.	Heat Flow during Explosion and Expansion.	Heat in Exhaust Gas at End of Expansion.
7	5·17	150	31·5	26·8	41·7
		200	32·2	25·1	42·7
		250	32·6	23·2	44·2
	5·70	150	32·8	27·0	40·2
		200	33·5	25·3	41·2
		250	33·8	23·5	42·7
	6·62	150	34·9	27·5	37·6
		200	35·5	26·0	38·5
		250	35·8	24·5	39·7
9	5·17	150	32·8	25·0	42·2
		200	33·5	23·2	43·3
		250	34·0	21·3	44·7
	5·70	150	34·1	25·3	40·6
		200	34·9	23·5	41·6
		250	35·4	21·5	43·1
	6·62	150	36·2	25·8	38·0
		200	37·1	24·0	38·9
		250	37·6	22·3	40·1
11	5·17	150	32·8	24·2	43·0
		200	33·5	22·6	43·9
		250	33·9	20·5	45·6
	5·70	150	34·1	24·5	41·4
		200	34·9	22·8	42·3
		250	35·4	20·7	43·9
	6·62	150	36·2	24·6	39·2
		200	37·1	23·3	39·6
		250	37·6	21·3	41·1

Discussion in London.

The President, in proposing a hearty vote of thanks to the authors for their very interesting Paper, said that a large amount of research had been made on gas-engines, especially on engines of about the size of that with which the authors had experimented; but there were still gaps in our knowledge, and the authors had certainly made a step in bridging at least one of those gaps.

The Resolution of thanks was carried with acclamation.

Dr. Dugald Clerk (Member of Council), in opening the discussion, congratulated the authors on a very useful piece of work which filled up, as the President had said, a gap in their knowledge on the subject. As the members were aware, he (Dr. Clerk) had interested himself for a very long time in everything connected with gas-engines. His earliest attempt at such an analysis as was given in the Paper, on the heat distribution in the cylinder, was dealt with in a Paper he read at the Institution of Civil Engineers in 1882. In the earlier days of work on internal-combustion engines, he studied the heat-losses incurred in closed vessels, using gaseous explosions with different proportions of gas and air. Experiments of that nature made as far back as 1886 gave interesting data enabling one to predict what sort of heat-loss would be obtained in large cylinders as compared with the small explosion vessel used for experimental purposes. In those days it was generally considered that if a mass of flaming gas were exposed to the interior surface of a chamber—a closed vessel without any moving piston—that given equal density and equal mean temperature, the loss would be proportional to the time of exposure—that is, if there was double the time of exposure of a gaseous explosion to cold walls, double the loss would be obtained. That idea was broadly true in cylinders having no pistons, namely, vessels of a constant volume.

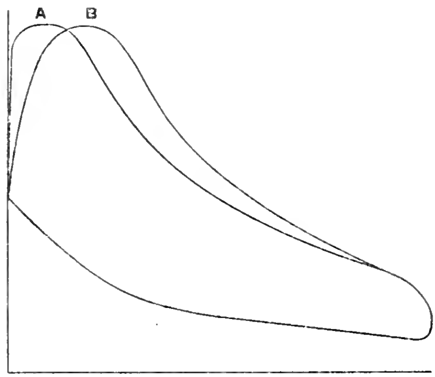
When experiments on actual engines began to be made, it was

expected that, if an engine ran at 100 revolutions per minute, and if the same engine then ran at 200 revolutious per minute, the conditions of the diagram, the flame temperature, and so on being exactly the same, the heat-losses would be very greatly diminished; they would be halved at 200 revolutions per minute, because the time of exposure was halved. It was very soon ascertained that this was not the case; in fact, under almost all conditions of running in actual engines, either in gas-engines or in petrol engines, the heat-losses seemed to change very little with the speed. Instead of diminishing, the rate of heat-loss certainly increased with the speed, and increased so much that it left very little improvement in the economy due to a higher speed. There was a speed in the engines where all the conditions (the conditions of the shape of the diagram more than anything else) gave the best results. In that case if the speed were increased, the rate of heat-loss was diminished so slightly that the expected economy was not obtained; the expected reduction of heat-loss was not forthcoming. For a long time that result was extremely puzzling; but some years ago several of those who were working for the British Association Committee on Gaseous Explosions, especially Professor Hopkinson and himself, found that the heat conductivity or the heat-loss in a cylinder varied very much with the rate of revolution. They made a number of experiments which seemed to show that the faster the engine ran, the greater the velocity the entering charge became in the cylinder, so that at a high speed it was easily possible to have an entering velocity as high as 150 feet per second. The idea among several of them was that that velocity persisted during the suction stroke and the compression stroke, and that when the engine was running fast the residual velocity movement in the cylinder at the moment of completion of compression was greater the higher the speed became. It was difficult to prove that that was actually so, but some experiments had now been made with an engine in which the valves were so arranged that the charge could be trapped. A charge could be taken in on an engine running at a certain speed, the charge trapped, and then the ignition prevented from occurring until the piston had moved two or three times out and in. In that

(Dr. Dugald Clerk.)
way time was given for the turbulent air to still down. Under those circumstances it was found that the ignition varied greatly. The ignition became much slower when the charge was trapped in that way than in the usual way.

Then Professor Hopkinson tried some other experiments, also with an engine. In that case he used the trapping device, but he measured the rate of heat-loss without putting in any gas at all, using air alone. He used a heated platinum wire and measured the rate of heat-loss, and he found that the faster the engine ran, even when the platinum wire was only opened at the end of the compression stroke, turbulence of the gases caused the rate of heat-

FIG. 7.



loss to increase with the rate of revolution of the engine. That at once showed that there was something in the nature of residual turbulence due to the inlet velocity of the charge. As far back as 1882 it would be found, from one of his old Papers, read at the Institution of Civil Engineers, that he was clearly conscious that there was a turbulence due to flame projection into a cylinder, but he was not conscious that the turbulence of the admission lasted to the completion of compression. Hopkinson found in addition that, if a fan were put in a closed vessel, the rate of cooling of the flame could be greatly increased by working the fan rapidly. He obtained velocities that represented the velocities in the cylinder, and identical heat-losses were also obtained.

The present Paper was exceedingly valuable, because it investigated a matter that others had not fully studied, namely, from the end of determining the variation of heat-loss due to variation in the rate of revolution, which was a very difficult matter to determine. He congratulated the authors on the care they had taken in that respect, and the care also they had taken with regard to the shape of the diagram. For an experiment of such a nature, it was necessary to be extremely careful not only that all the other conditions were absolutely right, but that different conditions of diagram were not obtained.

If an ordinary gas-engine diagram something like the diagram A, Fig. 7, was obtained, with a slightly rounded top, if in passing from one experiment to another, and from one speed to another, the same mixture was used and the rate of ignition was not altered, the diagram would change to B. The theoretical efficiency changed at once, so that a factor was introduced in which the added loss produced was not due to any change in the conditions of the cylinder, but the change in the position of the ignition-line. He noticed that the authors were careful about that, because they spoke in the Paper of keeping the ignition-line always straight. He presumed the authors never allowed the line to run forward in the manner shown in the diagram he had drawn.

Mr. W. J. Walker said the authors always took the precaution to obtain a vertical explosion-line.

Dr. Dugald Clerk said that was very important, because a comparison absolutely depended on the lines being kept practically the same. The authors had given them a series of most interesting results from that point of view.

Another interesting point in connexion with the Paper was that, in most determinations of heat distribution in a cylinder, the jacket-loss—the heat flowing from the combustible gases, the burning gases, to the water-jacket—included not only the heat which flowed during the explosion and expansion to the moment of exhaust, but the very considerable quantity of heat which also flowed from the exhaust gases into the jacket under the

(Dr. Dugald Clerk.)
exhaust-valve. He believed he (Dr. Dugald Clerk) first pointed out that cause of difficulty in a Paper which he read to the Institution of Civil Engineers in 1907, where he emphasized that to avoid this difficulty it was necessary to isolate the two water-jackets. He wished to point out that the authors in getting their engine made had the exhaust-valve part isolated from the rest of the water-jacket. It would be found that a description was given on page 364 showing that the exhaust-valve and the exhaust passage illustrated on the right-hand side of the diagram were surrounded by water, but were isolated from the water-jacket part B, so that in the A part they only obtained the small amount of heat which flowed through the cylinder-walls above the exhaust-valve, and a little to the left of the exhaust-valve in the vertical part they missed all the heat that passed into the jacket A, which was the heat that passed after the valve was lifted, when the gases passed under the valve and struck against the exhaust passage. In that way it was possible to isolate that portion of the heat, which should not appear in the balance-sheet at all. This appeared as heat lost to the sides of the cylinder, whereas it was heat lost after the moment of the opening of the exhaust-valve.

There was only one other remark he desired to make in reference to that experiment, namely, that it was rather difficult to isolate the loss in that way entirely. To be quite accurate, no heat should flow in through the exhaust-valve, and no heat should flow through the part near the exhaust-valve, only the heat coming after the exhaust-valve opened to make that a very good means of discriminating. He found, however, with much interest, that the authors arrived at a figure which he (Dr. Dugald Clerk) deduced from some of his own experiments with a peculiar type of diagram, which he called a zigzag diagram. He deduced from his own and from Professor Burstall's experiments that if the whole jacket-loss as determined in an ordinary engine were taken, about one-third of the loss was due to heat trapped under the exhaust-valve, so that where there was a jacket-loss in the old way of about 30 per cent., about 10 per cent. of it—the part going into the exhaust-valve or into the wrong place—was obtained in

that peculiar method. He noticed from page 379 that on the line of revolutions 200, which was the normal speed of the engine, with different quantities of air and gas, the amount of heat passing into jacket B was roughly 10 per cent., and that was not very far out from what was found to be the number deduced in the other way. That number, however, must be a little high. He believed the other, the third, was also high, for reasons he had previously discussed. Taking all the data given in the Paper, one who had been in the habit of experimenting on such subjects could appreciate the amount of work that the investigators had put into it, and he was very grateful indeed to find there was a great number of figures upon which it was possible to reason further.

There was one interesting point upon which it was possible to reason definitely, namely, it was possible to get from those determinations a fairly good idea of the specific heat of the different gases used in the engines. He presumed the total exhaust-heats were taken from the exhaust condenser.

Mr. W. J. Walker said they were; they were taken from the cooler.

Dr. Dugald Clerk asked if all allowances had been made.

Mr. Walker replied in the affirmative.

Dr. Dugald Clerk said that in that case, in all those figures where the total exhaust-heat on the charge was taken, it was possible to make further deductions. It was possible to compare that method of determination of the specific heat of the actual gases used in the engine with the rather more abstract methods which had now been used both on the Continent and in England in determining the specific heat of those gases and not in the engine cylinder at all. He thought the experiments he described some years ago at the Royal Society were the only experiments that had been made where the determination of the specific heat was made in the actual cylinder, but the authors' figures gave another method of making the same determination, and should be very interesting.

Professor H. HUBERT (Liége University) thought the Paper was one of the most valuable that had been written in the last few years on the subject of the distribution of heat in gas-engines. He admired the way in which the authors had condensed so much valuable information into so small an amount of space. He was quite sure that if the experiments had been carried out by engineers of another nation, they would have been explained in a large book with many references to other works, and the conclusion that these engineers alone knew the question.

He was glad to find that the authors had verified in their experiments the exactitude of a law which was not absolutely exact but nearly so, namely, that for a given engine working at full load the amount of heat lost by the exhaust gases and by the jacket was nearly constant. Professor A. Witz and himself had enunciated that law in the course of some experiments they had made on large gas-engines at the Cockerill Works. They had not tried it at different speeds, but they had tried it with reference to the temperature of the water entering the jacket, and found that there was hardly anything to be gained, because when one of the losses was diminished the other was increased, so that the sum remained constant. He found on referring to Fig. 5 (page 372) that the sum of the two losses at the two ends of the diagram was exactly the same, and it was the same also in Fig. 3 (page 370). It was interesting to know that it was very difficult to gain anything by increasing the speed, the number of revolutions per minute, and the brake horse-power. He and his colleague had found the same law in raising the temperature of the water issuing from the jacket.

He noticed from the Paper that the authors had measured the temperature of the expansion, not experimentally, but by two calculations, on the supposition that the gases only obeyed the general laws in regard to perfect gas. He wished to remind the members that one of his assistants, Mr. Duchesne, had measured exactly the temperature of the walls and of the steam in a steam-engine with very accurate thermo-electric thermometers, measuring the temperatures at each one-tenth of the stroke of the piston.

Without in any way wishing to criticize the method adopted by the authors, he suggested that it would perhaps be possible for them to have an exact measurement made, with Mr. Duchesne's thermo-electric thermometer, which had been described in the *Revue Universelle des Mines*,* the official publication of the Association of Engineers of the School of Liége. He hoped the authors would endeavour to secure the results of calculation by a direct measurement of the temperature at the end of the expansion.

He wished also to point out that, according to recent and unpublished experiments made in the laboratory of the *Fabrique nationale d'armes de guerre* (F.N.) at Herstal, near Liége, the thickness of the walls of a gas-engine had no sensible action on the wall-loss. Two engines, differing only by this thickness, which was in one case 7 mm. and in the other 25 mm., had nearly the same thermal efficiency of 18·5 and 18·8 per cent.

Mr. E. J. DAVIS desired to inquire whether the following statement made by the authors on page 376 was quite correct: "Since at 150 revolutions per minute the period of contact per cycle, of hot gases and cylinder walls, is 1·66 times as great as at 250 revolutions per minute, the rate of transmission of heat through the cooling surfaces is evidently much greater at the highest speed." Although the engine was running faster, was the speed for the working stroke in that proportion faster, because the cyclical variation of that engine at 150 revolutions would be considerably more than the cyclical variation of it at 250 revolutions, so that the time taken for the actual working strokes would certainly not be 1·66 times at the lower speed? The effect of this cyclical variation tended to lessen the difference in times of exposure of working fluid at the two speeds, decreasing 1·66 to some small extent. It was to be regretted that the indicator diagrams taken at the various tests were not given in the Paper, as these would have enhanced the practical interest. The back-pressure of the exhaust at the two speeds, if the valve-settings were the same for both tests, would affect the mixture and

* Tome vii, 4th Série (1904).

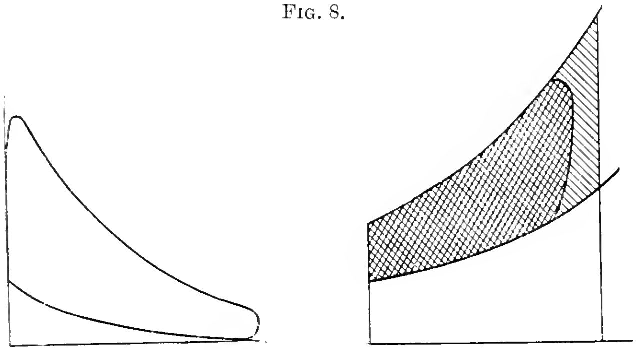
(Mr. E. J. Davis.)
temperature of the charge before ignition, tending to make the charge more inflammable at the higher speed. An extreme case of the effect of exhaust gases he (Mr. Davis) cited in the discussion upon Professors Coker and Scoble's Paper at the Institution of Civil Engineers on "Cyclical Changes of Temperature in a Gas-Engine Cylinder."

There was no evidence that the percentage of exhaust gases in the charge was higher at the higher speed, but if the settings were correct for 150 revolutions per minute, unless there was no back-pressure at the end of the exhausting stroke, it was difficult to understand how a homogeneous mixture could be obtained at both speeds. If, on the other hand, the first third of the diagram were taken and compared with the first third of a diagram taken at 150 revolutions per minute, and the average pressure for that portion was found greater at the higher speed, it would tend to show that the charge was more inflammable at the higher speed, in spite of the fact that a higher initial pressure was obtained at the lower speed. If the greater percentage-loss at the higher speed were due to turbulence of the fluid, one would expect the charge before ignition to be more inflammable and to increase the initial pressure, in spite of the higher speed, but from experience it was known that this was not so. Did turbulence before ignition have a marked effect upon the fluid after ignition, considering the fierce exchanges that must be taking place? The film of oil on the walls of the cylinder must have some effect upon the passage of heat. Were the conditions from this effect identical at both speeds?

Captain H. RIALL SANKEY (Member of Council) pointed out that the top curve in Fig. 3 (page 370) was called "Efficiency Ratio on I.H.P." That ratio had been obtained by dividing the thermal efficiency of the actual engine by that of the corresponding air-standard as defined by a Committee of the Institution of Civil Engineers, and was called the "Relative Efficiency" by that Committee. The air standard was based on pure air, assuming constant specific heat and taking a value for γ of $1 \cdot 4$. This standard was taken because at that time the knowledge of the

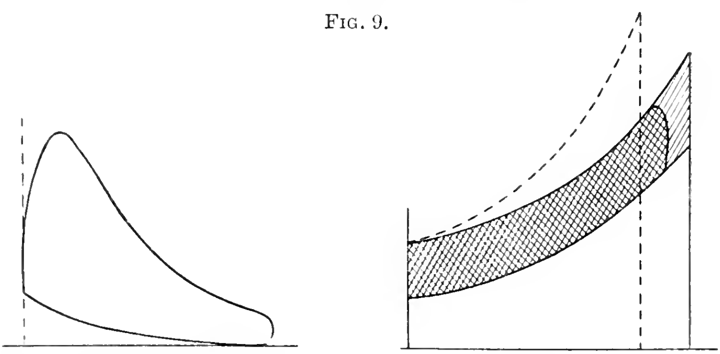
variation of the specific heat of gases was imperfect. Later on, due very much to the work of Dr. Dugald Clerk, Professor Hopkinson, and others, the law of the variation of the specific heat with temperature was determined, with sufficient accuracy to calculate the thermal

FIG. 8.



efficiency of an ideal engine using the working substance—that is, the product of combustion—and in the discussion on "The Third Report of the Gas-Engine Research Committee," Dr. Dugald Clerk gave a curve showing the thermal efficiency of an ideal engine using the actual working fluid for various ratios of compression. Thus for a

FIG. 9.



5·17 compression (the compression in the trials of Fig. 3), the efficiency was 39 per cent. instead of 48 per cent. for the corresponding air-standard. From Fig. 3 it would be seen that the thermal efficiency of the actual engine for the trial at 30 b.h.p. was

(Capt. H. Riall Sankey.)
33·5 per cent., and hence the ratio between what the engine itself did and what an ideal engine could do using the same working fluid was $\frac{33 \cdot 5}{39 \cdot 0}$, or 0·85. In the discussion on Dr. Dugald Clerk's Paper, to which Dr. Dugald Clerk had just referred, he (Captain Sankey) suggested that the expression "efficiency ratio" should be employed when the comparison was made with an ideal engine using the working fluid, in the following words: "He would suggest that 'relative efficiency' might be retained when comparing a gas-engine with the air standard, and 'efficiency ratio' should be used when comparison was made with the actual standard." Based on that, he suggested to the authors that they should also plot the "efficiency ratio" as above defined, and alter the words "efficiency ratio" given in the Paper to "relative efficiency."

Dr. Dugald Clerk had stated that in Diagram A, Fig. 7 (page 388), a better thermal efficiency was obtained than in Diagram B. The reason for this could be shown by the $\theta\phi$ diagrams, given in Figs. 8 and 9, which corresponded to a vertical and sloping explosion-line respectively. In each diagram the cross-hatched area represented the heat utilized by the actual engine, and it was obviously less in the latter diagram.

Mr. W. A. Tookey said he quite agreed with all that had been said in regard to the value of the Paper; it was one that could not be fully digested or even properly appreciated in the short time that the members had had the printed copy before them. He desired to ask a question in connexion with the calorific value given for town gas on page 367. The determination of calorific value was of great importance to manufacturers and others interested in gas-engines. It had hitherto been rather difficult to obtain a close comparison between calorific values determined by a calorimeter and those computed from figures. He noticed in the Table given by the authors it was stated that: "The corresponding lower calorific value (calculated) at standard temperature and pressure is 521·4 B.Th.U. per cubic foot. . . . The mean of the lower and higher values obtained during the trials were respectively

520 B.Th.U. and 577 B.Th.U. per cubic foot." It was quite evident that the authors had obtained a very close comparison between those two methods, one a computation and the other a measurement. When the Paper was finally printed he hoped the authors would insert the values they had taken for the different constituents that made up the total volume of the fluid. Using the values that were to be found in text-books upon the subject, and which had been based upon figures like Berthelot's, the calculated figure on the lower scale, for a gas of the composition mentioned in the Paper, would come out considerably less than the figures given by the authors, and he therefore suggested that in the final print of the Paper it would be interesting and valuable if the multipliers which the authors had used were added.

He thought it was a pity that the question of the different strength of mixtures was referred to only in the proportion of so many volumes of air to gas. A very much more useful comparison could be made when the figures were given on the actual number of B.Th.U. in a cubic foot of the working mixture entering the cylinder. Not only that, but knowing the ratio of expansion or compression to the engine—that is, the volume before compression to the volume after compression—one could compute the mixture strength of the working charge, taking into consideration the compression volume as well. That method of comparison gave an entirely different point of view. He had found personally that, using that basis, comparisons of tests gave a very useful means of comparing not only the performances of one engine, but the relative performance of many engines of different types working with gas and with other classes of fuel under various conditions. It was that universality or ability to compare engines operating with the different classes of fuel that was of considerable value to internal-combustion engineers. It might be remembered that, in the early part of the previous year, it was his privilege to read a Paper before the Institution upon "Commercial Tests of Internal-Combustion Engines." He then suggested that method of referring to the calorific value of the charge, and pointed out how on that basis it was possible to compare and to obtain a ratio

(Mr. W. A. Tookey.)
between the mean effective pressure produced to the heat entering the cylinder. That factor, as was pointed out by Captain Sankey at the time, could be used in another way for the determination of temperatures. It could also be used in another way. Knowing the strength of mixture, and knowing the factor for any particular compression-ratio, it was possible to obtain by calculation not only the mean effective pressure, but the useful pressure referred to the brake horse-power, and also, by difference, the pressure that had evidently been dissipated in overcoming the mechanical and fluid resistances of the engine.

For example: from Table 4 (page 384) the following comparisons were made possible:—

$$F \text{ (Tookey factor)} = E_{th} \text{ (Thermal efficiency i.h.p. or b.h.p.)} \times \frac{R}{R-1} \times 5\cdot4,$$

and for $R = 5\cdot17$; $F = E_{th} \times 6\cdot7$.

$\frac{\text{Air}}{\text{Gas}} = 7$ ∴ 520 B.Th.U. in 8 c. ft. of mixture, and 65 B.Th.U. per c. ft. of mixture admitted, equivalent to $65 \times \frac{4\cdot17}{5\cdot17} =$ 52·4 B.Th.U. per c. ft. of total cylinder volume.

R.p.m.	I.h.p. E_{th}.	I.h.p. F.	B.h.p. E_{th}.	B.h.p. F.	I.h.p. P_a.	B.h.p. P_a.	F.h.p. P_f.	Percentage increase. P_f.	Percentage increase of r.p.m.
150	0·315	2·11	0·277	1·855	110·5	97·2	13·3	1	1
200	0·322	2·155	0·274	1·835	112·8	96·2	16·6	1·25	1·33
250	0·326	2·18	0·256	1·715	114·1	89·8	24·3	1·835	1·66

$\frac{\text{Air}}{\text{Gas}} = 11$ ∴ $520 \div 12 = 41\cdot65$ B.Th.U. per c. ft. of mixture admitted, $= 33\cdot6$ B.Th.U. per c. ft. of mixture in total cylinder volume.

R.p.m.	I.h.p. E_{th}.	I.h.p. F.	B.h.p. E_{th}.	B.h.p. F.	I.h.p. P_a.	B.h.p. P_a.	F.h.p. P_f.	Percentage increase. P_f.	Percentage increase of r.p.m.
150	0·328	2·195	0·26	1·741	73·8	58·5	15·3	1	1
200	0·335	2·24	0·257	1·721	75·2	57·8	17·4	1·137	1·33
250	0·339	2·27	0·242	1·62	76·2	54·4	21·8	1·425	1·66

From the presentation of figures in this form it was clear that, with a rich mixture, there was, with increase of speed, a higher percentage of power absorbed in mechanical and fluid friction than with weak mixtures, and, moreover, that it was not in direct proportion with speed. From other tests made by the speaker, fluid friction appeared to be more accountable for the differences noted than did mechanical friction, and it would be interesting to know, from a study of the light spring cards taken by the authors, whether this was confirmed or not by their experiments.

By calculations from the thermal efficiencies given in Table 1 (page 381) it was also possible, by means of the Tookey factor, to obtain the values tabulated below, and by further computation the number of impulses per minute were calculable, so that it became possible to determine the value of P_f—or pressure absorbed in mechanical and fluid friction in "hit" cycles—and to correct it for the total number of cycles per minute which then rendered it comparable with the values of P_f in the Table on page 398.

$\frac{\text{Air}}{\text{Gas}} = 7$; R = 5·17; Impulses per min. $= \dfrac{\text{B.h.p.}}{P_a \times \text{I.h.p. constant}}$;

$$P_f \text{ corrected} = \frac{P_f \times \text{I.p.m.}}{\frac{1}{2}\text{ r.p.m.}}.$$

Load. B.h.p.	R.p.m.	I.h.p. E_{th}.	I.h.p. F.	I.h.p. P_m.	B.h.p. E_{th}.	B.h.p. F.	B.h.p. P_a.	Impulses per min.	F.h.p. P_f.	F.h.p. P_f corrected.	Percentage increase.
10	150	0·291	1·95	102	0·198	1·326	69·5	31·5	32·5	13·65	1
	200	0·295	1·975	103·5	0·172	1·152	60·4	36·3	43·1	15·65	1·145
	250	0·299	2·0	104·8	0·144	0·964	50·5	43·4	54·3	18·85	1·38
25	150	0·314	2·105	110·8	0·274	1·835	96·1	57	14·7	11·17	1
	200	0·317	2·125	111·3	0·255	1·708	89·5	61·2	21·8	13·35	1·195
	250	0·319	2·14	112·0	0·227	1·52	79·6	68·9	32·4	17·85	1·6

(Mr. W. A. Tookey.)

It would be evident from the foregoing that the increase of P_m and number of impulses per minute reduced the corrected values of P_f from 13·65 to 11·17 at 150 revolutions per minute when the output increased from 10 to 25 b.h.p. How much of this was due to the fluid friction falling off in relation to the ratio of "hit" to "miss" cycles could no doubt be deduced also from the light spring cards.

The PRESIDENT said that the worst feature of very valuable Papers was that their authors had so worked at the subject that there was very little left to take objection to. The Paper was an extremely valuable one, and he was sure the authors would be pleased with the general testimony which had been given to the importance of the research they had made, which had been one involving a very considerable amount of labour.

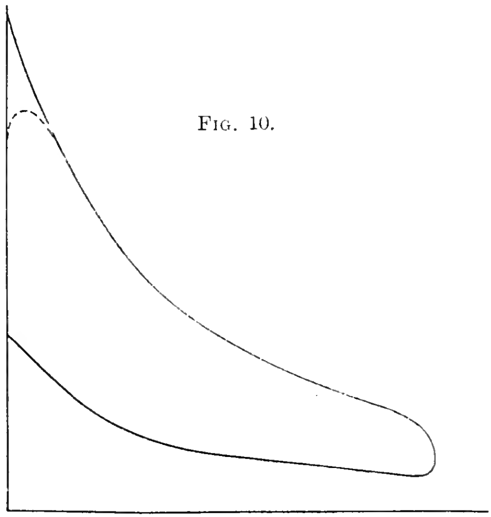
Mr. W. J. WALKER, in reply, after thanking the members for the very kind way in which the Paper had been received, said he would like to illustrate the types of diagrams which the authors obtained at different speeds when making the tests. Taking an ordinary case of a very slow speed and rich mixture, a diagram was obtained which had a sharp point, as shown in Fig. 10.

At the other extreme, when working with high speeds and weak mixtures (which tests were the most difficult to carry out), a diagram of the type shown dotted in Fig. 10 was obtained. The high speed and weak mixture gave a vertical line with a rounded top; it was impossible to get a sharp diagram under such conditions. When working at a speed of 250 revolutions per minute with a weak mixture, the engine sometimes stopped after running for about 5 or 10 minutes, owing to the weak explosions. Although some difficulty was experienced, the authors persevered, and possibly, out of about twenty tests at the highest speed and weakest mixture, half that number were obtained lasting from 20 to 30 minutes. The diagrams shown also illustrated the statement made on page 376, that at the high speeds the average temperature during the stroke was about 6 per cent. less than it

was at the slow speeds, and that accounted for the slight difference in the heat transmission to the jackets.

Attention had been called to the statement made on page 376. The words were there used: "With the strongest mixture, and at full load, the percentage heat transmitted to these jackets is 1·10 times as great at 150 revolutions per minute as at 250 revolutions per minute, while with the weakest mixture the ratio becomes 1·23." Turning to page 366, it would be seen

FIG. 10.



that the full load varied almost directly as the engine's speed. Full load was not a constant quantity with regard to speed. If it varied almost directly as the speed, then the energy involved per cycle must be the same in each case at both speeds, high and low, so that the quantity considered as constant on page 376 was not the load but the energy per cycle. It would be noticed that the statement was made on page 376: "With the strongest mixture and at full load." Although it might seem that the increased percentage heat transmission was due as much to increased load at higher speeds, yet such was not the case. When considering the

(Mr. W. J. Walker.)
effect of increased load upon percentage jacket-losses, it must be remembered that the increased load was obtained by decreasing the number of missed explosions, which was not the same thing as increasing the speed. Supposing they had the same energy per cycle at the different speeds, then the time of contact per cycle of the hot gases with the cylinder walls at 250 revolutions per minute was 0·6 times that at 150 revolutions per minute. The percentage heat-loss, assuming it to depend directly upon time of contact, should therefore be 0·6 times that at 150 revolutions per minute. As a matter of fact it was 0·91 and 0·813 in the two cases considered. Taking the slightly diminished temperatures at the higher speed into account, these two values of 0·91 and 0·813 would approximate to unity, hence the effective conductivity of the gases must have been increased in proportion to the speed.

On the other hand, taking two cases of load variation, say full load and three-quarter load at the same speed, it would be found that there was a diminished percentage jacket-loss at the lower load. That could not be ascribed to a shortened period of contact, as in the case of the difference in speed, but it was due to the cooling action of the air admitted during the missed explosion cycles, a condition which did not hold in the case of full load at different speeds.

Mr. Davis had pointed out that the cyclical variation of the engine speed at 150 revolutions per minute would be considerably more than the cyclical variation at 250 revolutions per minute, and that the effect of this would tend to lessen the difference in times of exposure of the working fluid. This was certainly true if the slower speed had been obtained at the expense of more irregular running. The comparisons made, however, were all at full load, and under such conditions the cyclical variation in the engine speed at different speeds must have differed very little. At lighter loads the cyclical variation in speed at the lower speeds was appreciably greater than at the higher speeds, but, then, no comparisons had been made between such cases. Any difference between the cyclical variation at full load and different speeds, if it did affect the question, must affect it to a small extent only.

The arrangement of jackets was a design of Professor Gibson's intended primarily for experimental purposes, and it was very instructive indeed to have the exhaust jacket-losses separated in that way. He would be very pleased to carry out Captain Sankey's suggestion, and alter "Efficiency Ratio" to "Relative Efficiency." * He intended to work out the actual values of the efficiency from the properties of the real working fluid, and it would be interesting to see the difference between the two. He would here mention that the $\frac{\text{air}}{\text{gas}}$ ratios were obtained from the meter readings, so that the actual figures of 7 : 1, 9 : 1, and 11 : 1 would be slightly larger, due to the dilution of the mixture by a portion of the exhaust products. In conclusion, he again desired to thank the members, on behalf of Professor Gibson and himself, for the kind manner in which the Paper had been received.

Discussion in Manchester.

The CHAIRMAN (Professor J. E. Petavel) said he was expressing the view of all present in stating that they were much indebted to the authors for bringing the matter before the Institution. The careful study of the internal-combustion engine was, of course, a subject of great importance. Professor Gibson was occupied with gas-engine research some four or five years ago when he was in Manchester, and he had had a very long experience of such experimental work. The internal economy of the gas-engine was extraordinarily complex, and to some extent many of the usual terms were liable to error. The errors of the indicator card had been discussed time after time, and everybody was in agreement as to the difficulties which arose in that direction. Another kind of difficulty arose from the large differences in so-called mechanical efficiency found by various people, but those

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* *See* footnote on page 370.

(Professor J. E. Petavel.)
discrepancies were largely due to the fact that the mechanical efficiency of a gas-engine could be made to vary to a very considerable extent by altering what did not belong to the gas-engine at all, but was simply in accidental relation to it, namely, the connexions, the exhaust-pipes, the gas-bag, etc.

Since Professor Gibson left Manchester they had been engaged in the Whitworth Laboratory on work in connexion with the gas-engine, and in conjunction with Professor Asakawa, who came from Japan to carry on such work, they had made a complete analysis of the losses. He thought it might add something to the discussion if he brought before the Meeting the result of this analysis. The first thing to remember was that, as was well known, only a part of the total heat was available, and that the system of comparing the efficiency of the gas-engine with that of the air-engine was purely artificial, for even a theoretically perfect gas-engine could only reach about 80 per cent. of air standard. This limit was fixed by the fact that the working fluid used in a gas-engine was not air, but a mixture containing CO_2 and H_2O, and that the specific heat of such a mixture was not constant but variable. When that was fully understood, they came to the conclusion that the margin of inefficiency remaining was very small. A study of the jacket-losses could not in itself throw much light on this question, because a heat loss through the jacket of, say, 5 per cent. or 10 per cent. occurring at the beginning of the expansion would be a loss of 5 or 10 per cent. in the efficiency; a loss of 10 or 100 per cent. occurring at the end of the expansion would be no loss at all in the efficiency. So it depended where the heat was lost.

He would now say something with regard to the question of the relative importance of the various losses. An ideal engine working with a compression-ratio of 4·85, and having no thermal or mechanical losses, would have a thermal efficiency of 47 per cent. on the air-standard, but only 36·7 if it used the mixture actually employed in an ordinary gas-engine. The point at issue was, how nearly did the actual engine approach to that ideal? They could divide the losses into two parts: one representing the

difference between the indicated h.p. of the actual engine and the indicated h.p. of the perfect engine, and the other representing what was usually put down as mechanical losses. The difference between the indicator card as drawn and that of an absolutely perfect engine was small, amounting only to about 10 per cent. of the latter, so that there was not much margin remaining. The engine behaved exactly as if 5 per cent. of the available power was lost before expansion—about a half per cent. during the explosion and 4 per cent. during the expansion. With regard to the mechanical losses, friction and valve-lifting represented about 11 to 12 per cent. of the total available energy, the windage of the fly-wheel about $1\frac{1}{2}$ per cent., and the pumping losses about 7 per cent. About half the pumping loss was due to the resistance of the inlet and outlet pipes, and hence the mechanical efficiency as usually defined depended to some extent on a factor not directly connected with the design of the engine.

Such an analysis of the losses might perhaps be of some practical value to designers, although one must admit it showed that the commercial engine approached already so nearly to the perfect engine working on the Otto cycle that much further gain was hardly to be expected. It was possible that in the future the gas-engine might be worked on a cycle which would render available considerably more than one-third of the heat, but this was a fundamental change which could not at present be regarded as a practical proposition.

There was one other point he would like to refer to, namely, radiation. Radiation was a factor which served to cover the errors made in the estimation of all other thermal quantities, and, as usually expressed, it had very little to do with actual physical radiation or loss of heat from the surface itself. In the present case he saw that the temperature of the outside surface of the engine-cylinder was kept constant. The radiation from the cylinder ought therefore to be constant. He did not know whether the authors assumed that to be the case.

Mr. Walker said that they did.

The CHAIRMAN concluded by expressing the hope that the Paper would lead to a really profitable discussion.

Mr. E. G. HILLER said he had the pleasure of knowing Professor Gibson before the latter went to Dundee, and always thought him a very able man, who, when he came to investigate these matters, would bring practical experience to bear on the subject.

When he heard the Chairman discoursing on the question of improvements in gas-engine design in the direction of efficiency, it seemed to him that the attention of the professorial gentlemen was turned in the wrong direction. He did not think the improvement of gas-engine design in the direction of efficiency was the most important matter at the present moment. The ordinary gas-engine was efficient as a heat engine but deficient as a reliable motor, and that was where the professors ought to give their attention. The search for efficiency in the sense used in the Paper might lead to incorrect conclusions as regards gas-engine construction and design. On Fig. 3 (page 370) it was shown that the mechanical efficiency, the thermal efficiency on i.h.p., the thermal efficiency on b.h.p., and the efficiency ratio on i.h.p., all increased with increasing loads. On the other hand, it had to be borne in mind that with increase of loads the reliability of the ordinary type of gas-engine, as measured by freedom from breakdown, decreased. Also on Fig. 5 (page 372), jacket-losses, and in Table 3 (page 383), radiation-losses, were shown to diminish as the speed increased. What, however, was the practical bearing of this effect? Was it desirable to reduce these losses in this way in a practical engine when the inevitable result of an increase of speed and increase of metal temperature was to increase the liability to mechanical breakdown?

Commercial competition had in recent years had a marked effect in this country in increasing the speed of revolution in the ordinary commercial type of horizontal gas-engine. Mr. J. G. Walthew read a Paper before the Manchester Association of Engineers last Session, in which he dealt with some of the more

commercial questions touching the design and construction of the gas-engine. In the course of that Paper he referred to the higher gas-engine speeds in connexion with which it had been found necessary to put balance-weights on the cranks. The history of it was as follows. In the first instance, gas-engine makers supplied a so-called ordinary type of engine running at about 160 to 170 revolutions per minute or thereabouts, and they sold an electric-light type of engine which ran at a higher speed with balance-weights. Of course the higher speed engine with more strokes per minute, having the same power developed per stroke, was more powerful than another engine of the same size running at a lower speed, and that was a commercial or selling factor.

The result of this factor was to cause a general increase in speed of the ordinary horizontal gas-engine in this country. Running at a higher speed, however, had increased the unreliability of these gas-engines though accompanied by a lower relative first cost and possibly a greater degree of thermal efficiency.

He had allowed himself to deal with questions not directly touched by the Paper, because he thought the professors were on the wrong line. For instance, the combustion chamber at the back end, at which some of the heat losses discussed in the Paper were measured, was one of the things that gave much trouble by cracking. In his opinion it was a more important matter that they should learn how to prevent such cracking of the casting in the valve-passages, combustion chamber, and liner than that they should try to get one or two per cent. more thermal efficiency, and the professors would do more for the development of the gas-engine by making it equal in reliability to the steam-engine than they would by confining their attention to the single question of thermal efficiency. There was much room for investigation in the direction of the improvement, in detail, of those castings, and in the qualities of different mixtures of iron, which if properly carried out should result in distinctly better working appliances being obtained.

He would like to refer to a defect in the design of the ordinary

(Mr. E. G. Hiller.)
gas-engine of commerce which was particularly objectionable in the larger sizes—namely, the adoption of the trunk form of piston. In the steam-engine it had been recognized for many years past that the cross-head was an essential part of the horizontal engine and it had a definite function to perform. In the large size of horizontal gas-engine the combination of the duties of piston and cross-head in the trunk piston led to objectionable results. It might be that with a cylinder of about 6 to 8 inches diameter the trunk piston was satisfactory, but when they came to cylinders of 16 to 20 inches diameter it was mechanically incorrect to throw on to the trunk piston the double duty of piston and cross-head, and this feature accounted for a large proportion of the cracked liners and other troubles which led to breakdowns in gas-engines.

The principal point which he desired to make clear was that investigations of the kind dealt with by the Paper were not directed to the most important of the questions which concerned the working of gas-engines. This criticism concerned not only the Paper before the Meeting, but also equally applied to others which had been published in relation to questions of a more or less academic character. The object of this expression of his views was to help in bringing about working improvements in the construction of the ordinary gas-engine and also to bring before the professorial investigators the desirability of dealing with the practical problems which concerned those who had, in their daily work, to deal with gas-engines and their failings and shortcomings.

Mr. H. N. BICKERTON complimented the authors on the Paper, which included valuable information, though it did not include what Mr. Hiller was always asking for. Every engineer who paid attention to gas-engine construction desired that improvements should be made, and they would be very pleased to have the help of the professors in bringing them about. At the same time it was not fair to say that the gas-engine was not a reliable motor; he believed it would become the most reliable motor in existence. The number that were now being used, the growing demand for them,

and the fact that manufacturers of them were very busy went to prove that statement.

Mr. ALFRED SAXON said he had prepared a few remarks on the general question of research work in connexion with engineering. The authors were to be congratulated upon the results of their investigations, which appeared to have been carried out in a careful and scientific manner. Their experiments, when studied, would go to prove how far the present gas-engine practice was right, and in what direction improvement might be obtained. As engineers, they ought to appreciate all research work and encourage it in connexion with whatever branch of the engineering industry it was undertaken, because it was evident that after a certain stage of development had been reached with any machine or prime mover, it could only be brought to a higher state of development by careful research work. The British engineers, he felt sure, had some leeway to make up, and if they did not carry out the necessary investigations, the foreigner would do it for them and reap the benefits. He wished to see the gas-engine made into a more perfect machine, if that were possible, than at present. His experience was that they found all kinds of prime movers required overhauling and repairing, and if one were guided in that matter by the experience of insurance companies (these remarks were prepared before the discussion that had taken place that evening), there was a much greater proportion of breakdowns and accidents in internal-combustion engines than in prime movers where steam was employed. He thought he was quite correct in saying that the area covered by the Manchester Association of Engineers formed the largest gas-engine manufacturing centre in the world, and any improvements in the gas-engine must have its effect on that large branch of the engineering industry of the district.

In concluding his remarks, he would like to call attention to one point in the Paper. In the comparisons the authors had made between the Hopkinson experiments and their own, the speed of the Hopkinson engine was given as 110 revolutions, whereas the speed of the authors' tests ranged from 150 to 250 revolutions.

(Mr. Alfred Saxon.)
Could any difference in results be accounted for by the difference in the speeds?

Mr. George E. Windeler (Stockport) said he was not connected with gas-engine manufacture, but he had something to do with the internal-combustion engine, his branch of it being the Diesel oil-engine. They were much indebted to the authors for the information they had given in their researches. The bearing these researches had on the subject, so far as manufacturers were concerned, was this, that all such investigations led them on to a new line of thought as to how they might approach the difficulties which were frequently experienced. The cracking of breech-ends or pistons on heat-engines had been a difficulty all engineers had to face from time to time, and the results of the authors' experiments tended to show how to approach the subject from another point of view and lead to further investigations of the troubles. In Manchester, which was the home of the gas-engine industry of the Empire, there were men who could tackle most problems as well as anybody abroad, and it was necessary, in his opinion, to approach the matter from the professors' point of view. Engineers had to look at it from a monetary point of view, but the professors bad not, and they could help forward the investigations in many ways. Naturally, insurance companies approached the subject from their own point of view. They had to provide for cracked pistons and cracked cylinder-covers; that was why engineers insured their engines—so as to be released from financial liability in case of breakdowns. Engineers were always open to receive suggestions, and if insurance companies would take up some form of research work as a means of assisting the industry to overcome the difficulties they had to face, it would be to the advantage of the insurance companies.

Mr. Frank Foster said that, although he had not intended to contribute to the discussion, it was turning in a direction which made him desire to say a few words. He appreciated work such as the authors described in the Paper. Before they could make

substantial progress with gas-engine design they must know exactly what thermal reactions were taking place inside the cylinder. When they knew where the heat went to, the next step would be to ascertain the wall temperatures; and when they had got the temperatures and the heat flow for the principal parts of the cylinder, they were not a long way from having definite information on which to modify and improve mechanically the designs now existing.

He wished to refer, in passing, to Fig. 5 (page 372), where there was something not exactly a mistake, but certainly misleading. The mechanical efficiency curve dropped very considerably as the speed increased. That was probably quite true of the engine tested, but it was not true of engines designed for different speeds; that was to say, if an engine designed for 150 revolutions per minute had a mechanical efficiency of 82 or 83 per cent., another engine properly designed for 250 would have a mechanical efficiency closely similar. He imagined the drop shown in Fig. 5 was due to extra fluid friction losses at increased speeds, mainly arising from valve-passages designed probably for the lower speed. At any rate one did not find in practice that the high-speed engine was specially low in mechanical efficiency.

Some engines he knew of were originally designed for a high compression, and on test they were found to consume about 8,800 B.Th.U. per b.h.p.-hour. That was a very low figure—in fact, probably a record for very large engines. Signs of trouble were noticed, and it was thought desirable to reduce the compression. It was reduced very largely—too much so in fact—and the consumption went up to approximately 10,000 B.Th.U. per b.h.p.-hour. For many years the proprietors ran the engines at that compression and with that gas consumption, because it gave them lower rates of heat transmission to the cylinder and piston walls—lower wall temperatures generally—and allowed improved working and lower overall costs. Later on they concluded that they had reduced the compression too far. It was somewhat increased and the gas consumption reduced. Those practical working results, he thought, had a direct connexion with

(Mr. Frank Foster.)

investigations such as the authors had made. He would like to suggest that, with the investigation of heat distribution, the authors should couple an attempt to estimate the temperatures and temperature fluctuations which occurred in the principal parts of the cylinder walls, the breech-end, and the piston; because, after all, those were the relevant factors which determined the working of the engine. On those points they had at present no very definite information, and therefore one was likely to stumble in applying information such as was given in the Paper, as there were several missing links.

He would like to suggest that, although the Paper was very useful, it did not go quite in the particular direction where it would be most useful. Mr. Bickerton claimed on a previous occasion, and he understood Mr. Hiller had agreed with him, that the very small gas-engine was now a most reliable machine. He was disposed to agree with that view. When they had double-acting cylinders of 50 inches diameter (as they were now made), with walls of cast-iron 3 to 4 inches thick, the pistons being water-cooled and having very high piston-speeds, thermo-mechanical difficulties began to be serious, although not insuperable. It was just there that they wanted to know what were the temperatures in the walls, what were the fluctuations, and at what points were they likely to get serious cracks and overheating. If the authors would throw some light upon such problems, they would really advance the gas-engine industry. It was possible to prosecute that class of research work without going to the expense of purchasing an engine costing £10,000 or £12,000. What they could do was to make a single cylinder of moderate size with very thick walls and pistons, put thermometers in and thermal-couples, and take measurements on those walls with various compressions and other conditions. Of course, the working conditions would not compare perfectly with those obtaining in large gas-engines, but still they would be much closer than at present with small experimental engines, and they would advance several steps towards obtaining information of vital value to the large gas-engine industry. If they could get something like definite information on points of that kind, engineers would

feel justified in making alterations in designs which might lead to the great desideratum of the gas-engine industry—reduced first cost. A reduction of 10 per cent. on the first cost of a gas-engine was worth more than an addition of 5 per cent. on its thermal efficiency. He would not say that was true of every individual case, but he thought it was true of the general run of large gas-engines. To be quite frank, the difficulty of selling large gas-engines was not on the point of reliability so much as of cost. They were so reliable that several works were relying solely on large gas-engines. The most modern types, if properly looked after, were almost as reliable as a steam cotton-mill engine. The great difficulty was that in order to obtain this reliability, the engine was so costly that in many cases it did not pay to install it. Therefore the progress of the large gas-engine in this country was very slow, and was likely to be slow unless by some means the cost could be brought down very considerably. The first step towards reducing the cost was to find out the temperatures in the walls; secondly, to discover the influence of variable thicknesses; and thirdly, to know the different qualities of metals in reducing the coefficient of expansion and the modulus of elasticity. When those points were solved, they would be able to make great progress. Till then he feared they would have to go very slowly indeed.

Mr. Daniel Adamson said that on page 376 the authors spoke of the "increased rate of transmission obtained in spite of a lower gas temperature," and said, "The reason is apparently to be found in the fact that the greater turbulence of the working fluid at the higher rates of speed increases its effective conductivity." There was no need for the authors to have inserted the word "apparently." An eminent predecessor of the Chairman of this Meeting, Professor Osborne Reynolds, studied the action of the principles of heat transmission many years ago, and the matter was very clearly put before them on many occasions by the late Dr. Nicolson in language (should he say) more suitable for consumption by the ordinary man in the street. Since then,

(Mr. Daniel Adamson.)
almost every Paper dealing with the question of heat transmission had pointed in the same direction, not only in the design of steam-generators, which was Dr. Nicolson's principal object in elaborating it,* but also in the design of electric generators it was found that the rate of cooling the parts of dynamos, which were subject to heating, varied directly as the rate at which the cooling air was passed over the surface.† They found that evening, as on many other occasions, the same fact brought to their notice. To put it in the authors' words, "it may be taken approximately that the effective conductivity was increased in the same ratio as the speed of the engine." He had Mr. Bickerton's authority in confirmation of that statement which he said was true. He would like once more to emphasize the great value of the work Dr. Nicolson did in that direction, and no doubt the authors would be able to confirm that remark.

Mr. J. DRUMMOND PATON said there was one question he would like to see referred to, and that was the radiant-energy transmission capacity of gases. There was no mention in the Paper of the relative capacities of the gases which were the result of combustion.

With regard to Mr. Daniel Adamson's references to Dr. Nicolson's work, the results obtained by Dr. Nicolson as to the transmission of heat from gases, he thought, went to prove that as they approached the velocity of transmission of radiant energy they increased the efficiency of heat production. The radiant-energy transmission was at the rate of something like 180,000 miles per second. The consequence was that if they got an immediate and open zone between the energized gas and the recipient body, they had radiant-energy transmission, and then again, where interception arose, linear velocity of the gases simply accelerated radiation.

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* *See* his Paper before the Junior Inst. of Engineers, 14th January 1909.

† *See* Symons and Walker's Paper, Inst. of Electrical Engineers, 25th January 1912, Vol. 48, page 674.

They ought to have some definition of the conditions under which the radiant effect was determined, and therefore located on cylinder walls. He referred particularly to the recent researches of Dr. Bone and the Bonecourt system. He thought they would find some solution of the transmission of radiant energy and the resultant product of heat if they actually analysed the radiant capacity of the various gases produced in combustion, and the zones in which they were formed.

Mr. Clifford Digby said it would add to the value of the Paper very considerably if the indicator cards were published along with the other data on page 366. From the figures given in the Table it was evident there was some throttling effect before the inlet-valve, as the power was very much lower in proportion with 250 revolutions than with 200. The maximum power as given even with the very rich mixture of 7 : 1 was much lower than was usual with an engine of that size. Under normal conditions, at 250 revolutions per minute the maximum power would be easily 44 b.h.p. If the light spring cards had been published, it would have been possible to ascertain directly whether the mechanical efficiency fall, which was very rapid at the higher speed, was due to that or not. In examining Table 2 (page 382) he noticed that the jacket-loss at 30 h.p. with a mixture of 7 : 1 was $19\frac{1}{2}$ per cent. against 16·1 per cent. with the 9 : 1 mixture, which was approaching the best mixture for economy. This would point to slow burning of the charge with the rich mixture necessary to obtain the higher power under the existing conditions. He thought that if the cards were published, a much better opinion could be formed of the value of the figures at the higher speed than was possible at present.

Mr. W. J. Walker, in the course of his reply, thanked the members for the way in which they had received the Paper and the various complimentary remarks made about it. The authors were well aware of the uncertainty attaching to the mechanical efficiency of a gas-engine, referred to by Professor Petavel, and in these trials

(Mr. W. J. Walker.)

comparison was made between three different methods of obtaining the mechanical efficiency, to see how they agreed. These were the ratio of b.h.p. to i.h.p. method, the "radiation" method,* and the "no load" method.* The first and the last agreed fairly well, but the radiation method gave values appreciably higher. Generally speaking, the average values of the first and last were taken. Professor Petavel also referred to the uncertainty of the value of the radiation loss. In the Paper, as stated, the radiation losses were taken as being the balancing quantities in each of the balance sheets. Some subsidiary tests, however, were also carried out according to the method outlined by Professor Hopkinson † for the measurement of radiation losses, and these agreed sensibly with the results obtained by balance.

It was also pointed out that increase or decrease of jacket-loss did not have a proportionate effect upon the efficiency. That was quite true. Dr. Dugald Clerk's Paper on "The Limits of Thermal Efficiency in Internal-Combustion Motors" ‡ first brought that point into prominence. At the same time that did not minimize the importance of the extent of these losses, since upon these depended the heat stresses set up in the jacket walls. This brought up a point referred to by Mr. Hiller (page 406) in connexion with efficiency and design, two factors which to some extent reacted upon one another and introduced the necessity of compromise. The efficiency of a gas-engine might at the most be increased by a small percentage, but the design of cylinder-jackets, more especially for large cylinders, was a question of greater importance than increase in efficiency. In the Paper the authors, with the desire to keep down an unwieldy mass of figures, had not given the divisions of heat flow in the various sections, namely, cooler, breech-end, barrel and exhaust gases, but no doubt these would be dealt with in a future Paper.

* Proceedings, Inst. C.E., 1906, vol. clxiii, page 241.

† Proceedings, I.Mech.E., 1908, page 417.

‡ Proceedings, Inst. C.E., 1907, vol. clxix, page 121.

Mr. Hiller also referred to the desirability of research being carried on along the line of obtaining this increased reliability. He would like to point out, however, the difficulty which confronted those engaged in research in educational institutions. This difficulty was the one of obtaining apparatus which would be useful from both an educational and a research point of view. At the same time, he held that although it was not always possible to get the apparatus which was wanted, yet a good deal could be done with what was already installed.

Mr. Foster referred (page 411) to the mechanical efficiency of the engine decreasing so appreciably with speed, and expressed the opinion that that would not occur in engines which were designed to run at their own particular speed. With that opinion he (Mr. Walker) agreed to a certain extent. If an engine were designed to run at 200 revolutions per minute, then at 250 revolutions per minute its mechanical efficiency would be decreased by the increased resistance offered by the exhaust-pipe and valve-passages designed for a slower gas-speed. The pumping-losses would be increased. At the same time he thought that the mechanical efficiency of an engine designed to run at a higher speed would be decreased, although not nearly to the same extent as in the present case.

A question was raised with regard to the Table at the top of page 379. The engine used by Professor Hopkinson had a speed of 110 revolutions per minute, as compared with the 200 revolutions per minute of the Dundee engine. Personally, he did not think that the comparison would be appreciably affected; although the speed was lower, the relative figures would remain practically the same.

With reference to the statement on page 376, which read, "it may be taken approximately that the effective conductivity is increased in the same ratio as the speed of the engine," it had been stated that that was an effect already obtained in experiments on the variation of heat transmission with gas velocity. Most experiments of this kind had been carried out on tubes of relatively small diameter compared to length, and did not conform to the case of a gas-engine

(Mr. W. J. Walker.)

where there was a relatively large diameter. It was really a question as to whether convection or radiation was responsible for the larger share of the heat-loss. The work of Professor Hopkinson and W. T. David * on the radiation of gases showed that radiation was responsible for the loss of somewhere about 25 per cent. of the heat of combustion. How this proportion varied with ratio $\frac{\text{diameter}}{\text{length}}$ had yet to be determined. Turbulence, of course, seemed to indicate an increase in heat convection, but in view of the large proportion due to radiation, it seemed strange why convection should exert such an appreciable effect with increase of speed. He would suggest the following explanation. The proportion of heat radiated from the gas was unaltered by an increase in speed, but the passage of this radiated heat through the walls was facilitated by the increased scrubbing action of the gases at the higher speeds. The problem, however, was one to be solved by experiment. In conclusion, he desired to thank the Manchester members for their appreciation of the Paper and the interest they had shown in it.

Professor A. H. GIBSON, who holds a Commission in the Royal Field Artillery, wrote expressing his regret at his unavoidable absence from the readings of the Paper and his appreciation of the way in which it was received both in London and Manchester. Owing to the strenuous work in camp he found that he had no time available to deal with the Discussion, to which he thought his co-author, Mr. Walker, had effectively replied.

* Phil. Trans. Roy. Soc., Vol. 211, page 375.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JUNE 1915.

A SPECIAL MEETING of the Institution was held at The Institution of Civil Engineers, London, on Friday, 11th June 1915, at Three o'clock p.m., in response to a Requisition signed by 56 Members and Associate Members (under No. 14 of the Articles of Association) to consider a Motion by Mr. E. W. PETTER, *Member*.

The requisite quorum of thirty Members and Associate Members being present, the SECRETARY read the notice convening the Meeting, as follows:—

"2nd June, 1915.

"Dear Sir,

"In accordance with No. 14 of the Articles of Association, and in response to a Requisition signed by 56 Members and Associate Members, the Council hereby convenes a Special Meeting of the Institution on Friday, 11th June 1915, at 3.0 p.m., at The Institution of Civil Engineers, Great George Street, Westminster, for the consideration of the following Motion to be moved by Mr. E. W. Petter, *Member*, of London:—

"That, in view of Paragraph 3 (sub-sections A and B) of the Institution's Memorandum of Association, the highly technical character of the War and the dependence of the Allied Forces on the products of mechanical engineering, it is desirable that the Institution should in its corporate capacity endeavour to assist the Country by making arrangements for receiving from its members particulars of inventions relating to apparatus likely to be of service in prosecuting the War, improving means of production, or otherwise, and considering, inspecting, reporting upon, and, where considered desirable, bringing the same to the notice of the Government."

The PRESIDENT pointed out that, in accordance with the Articles of Association, no other business could be transacted than that on the notice convening the Meeting. He gave a short statement as to the contents of some letters with reference to the Meeting which had been received from members unable to be present.

Mr. E. W. PETTER: Mr. President, Members of Council, and Gentlemen. I rise to propose the motion which has already been read to us by the Secretary.

Before addressing myself to the question, I would like to say with what pleasure one sees that a matter which has been the subject of a good deal of heart-searching on my part is one also of considerable interest to the members of the Institution, as evidenced by the large attendance at this Meeting. I may add that I also received seventy letters this morning by the first post from members who are unable to be present, and I am also glad to say that, although I have only had a chance of glancing through them, there are certainly one or two suggestions in those letters of a very much higher order than those which were read to us just now.

I am not sure that it is necessary for me to detail the circumstances which have led up to the point of calling this Special Meeting, but I should like to say this, that it is just three months ago to-day that I first addressed the Council on the subject of doing something as an Institution and as a body of trained engineers to assist the country at the present juncture. When the last Ordinary General Meeting of the Session was held I was asked to move a resolution of an ordinary business character relating to the appointment of an Auditor, and I asked then if I might be allowed to speak very informally on this subject also; but it was not felt desirable that I should do so. Well, gentlemen, it was the last chance of our being together, and therefore this Meeting comes to be held. One of the difficulties which a member finds himself confronted with in moving in a matter of this kind from outside the Executive of the Institution is that of appearing to be in any way taking up an attitude of hostility towards the

Council. In sending in the requisition for this Meeting I expressly disclaimed any such feeling, and I do so again now. If we as an Institution are in any way to blame for anything we may not have done that we might have done, we, the ordinary members, fully share the responsibility, because the Council, as we all know (some of us are members of similar bodies), find it very difficult to move unless they are quite certain that they carry the general body of members with them. Therefore I am not here to-day to impute any blame to anybody, but to put before you a motion which I think cannot but be beneficial to the country at large, and particularly to our Institution, to which we are all so much attached. I do think that if at the commencement of the War we had met in the way we have met this afternoon and had considered the War from a mechanical engineering point of view, it might have had some effect upon the course of the War. I think perhaps the advice of this Institution might have saved the country the loss of something like 30 per cent. of its skilled mechanics who have been sent out to the Front to fight, and many of them to die, when they might have been very much better employed at home. One other point on which I think we might have given very valuable assistance to the Government when they realized the difficulties connected with munitions is this. We might have pointed out to them the great advantage of reserving certain factories for the manufacture of such things as jigs and tools, so that when any new factories were taken over, as is being done almost every day, instead of sending the drawings and telling people, who are probably very badly equipped with facilities for making tools, to make their own tools and jigs, these people would have had the jigs and tools sent down with the order, and would have been able to get on with the work at once. I put this forward just as a suggestion which might have been of great value if we had been in the position to make suggestions, and if we had felt that our suggestions would receive attention, and as one point among many in which we, as an Institution, might have assisted the country.

I wish you to notice that the motion which I have put on

(Mr. E. W. Petter.)

the paper for to-day deals with one subject, and one subject only, namely, the subject of invention. There are no doubt other subjects which, at any rate, we might have assisted in, as I have already indicated, but I think the great stir in the matter of organization which has taken place during the last three months, and the great and valuable work that has been done since then, makes it undesirable, and probably not possible, for this Institution to interfere in the matter of organization. But on this question of invention, which is not only equally important, but in some cases more important, I do feel we have a power to help which no other body of men in the country has, if only it is properly used. In case any gentlemen here present have not read the Articles referred to in the motion, I think it is well to read them now, because these Articles represent the fundamental basis and foundation upon which this Institution stands. Paragraph 3, Clause (A), of the objects for which the Institution is formed states: "To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large. (B) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects." I have read those extracts in order to show that the motion deals with almost the one and only subject referred to, which is the basis of the foundation of the Institution and of its work.

There is another remark I would like to make, namely, that this motion has not been brought forward to further any private interests. If anything is going to be done for the common good, there are always plenty of people who try to rush in and serve their own interests, but that is not the object of this motion. It is to seek to find out inventions of public utility at the present time. I am quite sure that any Committee formed to carry out this resolution will be able to deal with the difficulty of people trying to further their private interests instead of those of the State.

The reason for this motion is also stated within it—"the highly technical character of the War and the dependence of the Allied Forces on the products of mechanical engineering." I do not suppose there is anyone here present who has been following the War with any closeness at all—as I am sure we all do—who does not realize that there is a real need for invention at the present moment. The War is a new experience to every one of us, and it has brought with it new problems, and is every day adding to the new problems which have to be faced. One of the most remarkable things—and yet it is not remarkable to those of us who know anything of German education and training—is the extraordinary mechanical genius of our enemies. I do not think a week passes, in fact hardly a day passes, but what we hear of new mechanical devices and contrivances which they, in the pursuit of turning their genius to the subject of destruction in warfare, have evolved. I do not suppose it is necessary for me to enumerate them. I have a list here, and I will mention a few of them—their large submarines and Zeppelins, interchangeable shells, prismatic lenses for periscopes, new explosives, star shells for use at night, new automatic gun-sights. All these things, and a good many others, we hear of every day, so that, as was stated in one of the London papers yesterday, we may say that the Germans are looking to their scientists to win their battles more than to their generals. And that is, I fear, what we are not doing in this country. The fields of aviation, mechanical transport, submarine warfare, weapons of offence and defence, all depend on the genius of the mechanical engineer, and those are the things to which I consider we as an Institution ought to devote our attention intelligently and sanely, to see if we cannot solve some of these problems and produce something which shall be novel and valuable.

I contend that this Institution has great ability to assist in its corporate capacity. Our Institution comprises within its membership mechanical genius in no way inferior to that of our enemies, but it needs better organization. This Institution has an organization ready formed, with members eager to assist, but requiring leadership.

(Mr. E. W. Petter.)
The President said we had over 6,000 members, a very large proportion of whom are eager to assist at the present juncture. We are told, I think in last month's Journal, that over 400 of our members are serving in His Majesty's Forces. We honour the 400; but, gentlemen, I am not sure that the 5,600 at home ought not to be serving also in His Majesty's Forces in a different way. I do not consider that we as an Institution have any right to take credit for the individual work of our members. It is in our corporate capacity that we should assist. I have had the opportunity of having explained to me some of the work which has been done by our esteemed President and Members of the Council. I know the anxieties and the activities of many of these gentlemen, but I feel in regard to that that the individual work of any Members of the Council does not absolve them from the responsibility to use the organization of the members.

With regard to this question of inventions, I know—we all know—that both the War Office and the Admiralty have an organization for dealing with inventions, and I am told that together they are receiving something over 175 inventions a day, nearly double the number which the Patent Office has to deal with. Of course, they cannot read them, they cannot touch them, and the result is that trained engineers sending in their ideas to the Government receive no better consideration for their sane ideas than any lunatic for his wild dreams. They are all turned down, and many of us know the result. I do not think it is disputed. The reason for that is that the Government are receiving particulars of inventions from all and sundry, from the public at large. Every other man you meet thinks he has some panacea to relieve the Government from its military difficulties and himself of his financial embarrassments. This question of inventions, I contend, is not being dealt with at all. The machinery which is intended to deal with it is absolutely clogged. I ask you to note most particularly those words in the motion, which say that the idea is that inventions shall be received by the Institution "from its members." I believe we can trust our members not to send in undigested and immature ideas, and, even if they do, means can be found for ruling them

out. Are we going to turn down all the possibilities to assist, which this Institution has, because of a few scatter-brained individuals who are sending in things not worth the paper upon which they are written? We shall make a very great mistake if we do anything of the sort. The Institution has power to help, and means should be found, and must be found, to enlist the help of the humblest member of the Institution, as well as the most exalted. Many of our more humble members are engaged in work where they have an insight into things that others have not, and if the Institution organizes these members we shall have a chance of passing on to the Government something which may be of incalculable value to the country. I would like to point to the example mentioned in the April Journal. It was suggested to the Institution that the War Office would be glad to receive designs for mechanical bomb-throwers. In response to an announcement to this effect in the Institution Journal, twelve designs were received, one of which had special merits, and the thanks of the War Office were tendered to each member who sent in a design. I call this sane inventing. A need is propounded; it is placed before a body of trained engineers who set to work and cudgel their brains, and send in a number of designs which I think the Journal indicates were valued by the authorities who called for them.

Before resuming my seat, I feel that I ought to deal with the possible arguments against the motion. We shall no doubt hear them presently, but perhaps by a little anticipation, if you do not mind, I would like to touch on one or two of them. It may be we shall be told that no desire has been expressed by the Government for this action on our part. That may be so. The Government may not have any idea of our capacity to assist. Sometimes if you see a friend in trouble, and you are in a position to help him, it is a good plan to lend the assistance before he asks for it, and let him find it out afterwards—especially if he is in the water. The Government may not know of our organization as it does exist—practically all the mechanical engineers of the country waiting to be called together to render assistance based upon education, training,

(Mr. E. W. Petter.)
and experience. Another objection may be the enormous amount of time, and perhaps money, which the carrying out of this motion would involve. I am not prepared to dispute it. Even drawing the ideas from our own members will be no doubt a big task, but I do not know that we ought to measure it by the greatness of the work. I think it should be measured by the possibilities of the result. I know we have a great many members—and I have been told so also by our Secretary—who are ready and anxious to join in any movement which may be inaugurated for the benefit of the country, and I believe if this thing is taken up in a whole-hearted and decisive way there will be no lack of helpers coming forward to make it work successfully. With regard to the cost, how can we spend our money better, if this is a sane resolution, if it is a sane idea, than in working it and thereby promoting the interests of the country? The Institution has a subscription income of over £15,000 a year, and I do not think in this year 1915 we can spend a portion of that money better than in endeavouring to find out something to assist us in prosecuting the war successfully. Organization is in the air, and the question I ask myself, and which I ask you, gentlemen, is: Who is going to organize us? Are we going to be gathered into all kinds of organizations which will take no notice at all of our training and experience, or shall we organize ourselves for a specific purpose and endeavour to carry that specific purpose to fruition? I strongly commend to you that the latter is the right course for an Institution of this standing to take. I do not suppose there is a single one here present who is not actively employed in His Majesty's Forces who has not asked himself again and again during the past few months whether his actions at the present time are such as he will contemplate in the future with satisfaction. I ask the same thought for our Institution. We have reared for ourselves a magnificent building in Westminster, of which we are justly proud, because we feel that it expresses the importance of our calling. Let us see that in this supreme time we show the world that it has not been built for nothing, and that instead of vacating our Institution we use it, and use it well, for the benefit of the country. That is the sole idea and only object

I have had in being the prime mover in calling you together to-day. I now have the pleasure, Sir, to propose the Motion.

The Motion was seconded by Mr. Lelean.

The President read letters from Sir John Wolfe Barry, K.C.B. (*Member of Council*), and Mr. George Hughes (*Member of Council*).

A considerable discussion followed, in which the following members joined:—Messrs. R. Mathot, C. E. Stromeyer, Captain H. Riall Sankey (*Member of Council*), Leslie S. Robertson, Henry Davey (*Vice-President*), Walter Carter, James Carson, J. T. Bateman, E. C. de Segundo, Sir J. Alfred Ewing, K.C.B. (*Member of Council*), Charles Wicksteed, Mark Robinson (*Vice-President*), R. E. Ellis, and Hal Williams.

It was moved and carried that the question be now put; and after Mr. Petter had replied to the discussion upon his Motion, the President asked for a show of hands and declared that the Motion was lost; 66 voting in favour, and 99 against.

The attendance was 275 members.

MEMOIRS.

WILLIAM EDGAR ALLEN was born in 1837. He was sent at an early age to Paris, where he received his education at the Collége Chaptal. He went later to Holland and Germany, and subsequent residence in Spain, Portugal, and Italy enabled him to speak most of the European languages. Previous to starting in business for himself, he travelled over the Continent as representative for Messrs. Ibbotson Bros. and Co., of Sheffield, steel and railway plant manufacturers. In 1868 he founded the firm of Edgar Allen and Co., Imperial Steel Works, Sheffield. Taking advantage of his knowledge of Continental firms, he soon obtained extensive orders for foreign arsenals, dockyards, railway companies, etc. In 1890 the business was converted into a limited company, of which he was chairman, but he otherwise retired from active participation in the conduct of the business. Besides other donations, Mr. Allen gave, in 1909, the Edgar Allen Library to the University of Sheffield, and founded, in 1911, the Edgar Allen Institute for medico-mechanical treatment, in Sheffield, the first institution of its kind in this country. This has proved especially beneficial during the present war, a great number of soldiers having recovered the use of their limbs through the efficacy of the treatment. He was one of the oldest Freemen of the Cutlers' Company, having been elected in 1870. His death took place in Sheffield on 28th January 1915, at the age of seventy-seven. He was elected an Associate of this Institution in 1880.

FREDERIC GORDON AYERS was born at Adelaide, Australia, on 2nd September 1871. He was educated at the Collegiate School of St. Peter, Adelaide, from 1881 to 1889, and in 1890 received private technical instruction from the Lecturer of the Technical School at the same city. He was apprenticed to Messrs. Fulton and Co., Adelaide, from 1891 to 1896, when he became assistant manager to

the firm. During his apprenticeship he attended lectures at the School of Mines. In 1897 he went to Tasmania as assistant engineer to the Mount Lyell Mining and Railway Co., and in 1898 became assistant manager to Messrs. Fulton and Co. He left this firm in 1899 to obtain further experience in England, and returned to Australia about 1901, when he was engaged on the designing of new locomotives for the South Australian Government. After this he was for two years as assistant engineer on the construction of the Fremantle tramways in Western Australia. His next engagement was as Overhead Superintendent for the construction of the Adelaide tramways, which post he held until he resigned, to come to England for a holiday, returning to Australia in June 1914. His death took place in Australia on 2nd February 1915, in his forty-fourth year. He was elected an Associate Member of this Institution in 1901.

Charles Edward Chrimes was born at Rotherham in September 1839. He was the principal of the firm of Guest and Chrimes, Foundry and General Brass Works, Rotherham, and for over sixty years had been associated with the firm, of which he was sole proprietor for a number of years previous to his death. It was due to his efforts that the works maintain their high reputation. He took a great interest in any improvement introduced to the various inventions and articles produced at his works, and devoted much time to the care of his employees, many of whom had been employed by the firm during the whole of their working career. His death took place at Rotherham on 28th November 1914, at the age of seventy-five. He was elected an Associate of this Institution in 1888.

Frederick Colyer was born in London on 26th June 1833. As a young man he was connected with gas and water undertakings, and later became a partner in the firm of George Waller and Co., engineers, of Southwark. In 1880 he started in practice in Westminster, as a brewers' consulting engineer, under the style of Scamell and Colyer, and from his designs the following breweries were erected: Stretton Bros., Derby; Peter Walker's

Trustees, Burton-on-Trent; Royal Oak Brewery, Croydon; Dudney and Son, Portslade; John Smith, Tadcaster; and additions to the City of London Brewery. He was the author of many books on engineering subjects, among which may be mentioned: "Breweries and Maltings" (in conjunction with George Scamell), "Pumps and Pumping Machinery," "Gasworks Construction," "Modern Steam-Engines and Boilers," "Hydraulic, Steam, and Hand-power Lifting and Pressing Machinery," "Public Institutions, their Arrangement and Plant." His death took place at Ryde, Isle of Wight, on 2nd December 1914, in his eighty-second year. He was elected a Member of this Institution in 1878; he was also a Member of the Institution of Civil Engineers, and a Fellow of the Surveyors' Institution.

GEORGE D. DENNIS was born at Colchester in February 1848. He served an apprenticeship from 1863 to 1868 with Messrs. Catchpool and Thompson, engineers, of Colchester. From 1870 to 1878 he was with the Stockton Malleable Iron Co., Stockton-on-Tees, and from 1878 to 1889 mechanical engineer to the Derbyshire County Council. In 1889 he became superintendent engineer to Messrs. Whiteley and Co., Westbourne Grove, London. His death took place on 20th January 1915, in his sixty-seventh year. He was elected a Member of this Institution in 1892.

WILLIAM ROBERTS ECKART was born at Chillicothe, Ohio, on 17th June 1841. He was educated at schools in Chillicothe and Cleveland, and took a special course in mathematics to fit him for the profession of civil engineering. On his father removing, in the middle of the "Fifties," to become manager of the Putnam Flour Mills, at Zanesville, Ohio, he began an apprenticeship in the works of Griffith, Ebert and Wedge, a firm which held a high reputation in those days for general mill and steamboat work. During this period he secured the friendship of the junior partner and manager—Mr. Wedge—who was a master mechanic of great ability, and had been an apprentice and foreman to Sir Joseph Whitworth when the latter was making known to the world his

most accurate methods of machine-tool construction. During his apprenticeship he made numerous trips on the trials of new river-boat engines, which led to his desire to enter the United States Navy as engineer. On the outbreak of the Civil War in 1861 he was appointed third assistant engineer in the fleet on the Pacific Coast, and remained in the Navy until 1864, when he resigned on account of ill-health, taking up his residence in San Francisco. He then became chief draughtsman for H. J. Booth and Co., mining and marine engineers, and in 1865 he designed and built the first Californian locomotive. In 1869 he became draughtsman to the steam-engineering department at Mare Island Navy Yard, subsequently being promoted to the position of Superintendent of Steam Machinery. Two years later he left the Navy Yard to enter into partnership at the Marysville Foundry, which had a large business in hydraulic, milling, and mining machinery. In 1878 he moved to Virginia City, Nevada, and became consulting engineer to the "Bonanza Firm," which controlled nearly all the North End Mines; he was also appointed U.S. Deputy Mineral Surveyor for the State of Nevada, and a member of the U.S. Geological Survey. Much of the hydraulic and mining work he undertook was of a pioneer class, as no similar conditions were known. In 1880 deep mining began to decline, and Mr. Eckart removed to San Francisco, where he acted as consulting and constructing engineer, and during the next ten years some of the largest mining plants were designed and constructed under his supervision. When the U.S. Government began building warships for the new navy, and the Union Iron Works, San Francisco, secured contracts in 1890 for a large number, Mr. Eckart was appointed consulting engineer, and assisted in conducting the preliminary and government trial trips. In 1899 he was appointed consulting engineer to the Standard Electric Co., and afterwards also had charge of the construction department. On the acquisition of the property by the Pacific Gas and Electric Co., he was retained as consulting engineer in connexion with the hydro-electric branch of their work. At the end of 1913 he retired from active business, but continued in the employ of the Pacific Gas and Electric Co.

up to his death, which took place at Palo Alto, California, on 8th December 1914, at the age of seventy-three. He was elected a Member of this Institution in 1878. He was also a Member of the American Society of Civil Engineers, the American Society of Mechanical Engineers, and other American Societies.

SAMUEL FOTHERGILL WATSON FOTHERGILL was born in London on 23rd December 1874. He was educated at Elstree and Harrow, and served an apprenticeship of two years, 1891–1893, with Messrs. Reader and Sons, Nottingham; of three years on the Somerset and Dorset Joint Railway, 1893–1896; and of two years with Messrs. Maudslay, Sons and Field, 1896–1898. In the latter year he became managing director to Messrs. E. Reader and Sons, and was holding this position at the time of his death, which occurred on 16th January 1915, at the age of forty. He was elected an Associate Member of this Institution in 1904.

GEORGE ROBERT WILLIAMSON JONES was born at Leeds on 17th March 1874. He was educated at Askern College, near Doncaster, and from 1888 to 1895 served his apprenticeship with Messrs. Clayton, Son and Co., Ltd., Leeds. In May 1895 he went out to Pernambuco as engineer on his father's gas works, and when the latter died in 1900, became manager. He held this post till 1910, when he resigned and joined the Great Western of Brazil Railway Co. as a contracting engineer, which position he was holding at the time of his death, which took place at Leeds on 11th February 1915, in his forty-first year. He was elected an Associate Member of this Institution in 1906.

ARTHUR KEEN was born in Cheshire on 23rd January 1835. He commenced his business career on the London and North Western Railway, being promoted in a short time to be goods agent at Smethwick. Whilst holding this position he entered into partnership with Mr. Watkins, the inventor of a nut-making machine. This venture proved entirely successful, and in 1864 the original firm of Messrs. Watkins and Keen was converted into the Patent Nut and Bolt Co. In 1900 this Company purchased the Dowlais Iron Co, including their works and mines,

and, amalgamating with Messrs. Guest and Co., colliery owners and iron and steel manufacturers, became Messrs. Guest, Keen and Co., of which Mr. Keen was Chairman and Managing Director. This new concern soon acquired the business of Messrs. Crawshay Brothers, Cyfarthfa, Ltd., iron and steel makers and colliery owners, and almost at the same time amalgamated with the firm of Messrs. Nettlefolds, the title of the firm becoming Messrs. Guest, Keen and Nettlefolds, Ltd., of which Mr. Keen was Chairman. Together with this duty he performed that of Director to Messrs. Bolckow, Vaughan and Co., while he was also Chairman of the New Cransley Iron and Steel Co., Director of the Loddington Ironstone Co., and Chairman and Director at successive periods of Muntz's Metal Co. His connexion with the last two firms eventually ceased on his finding that his time was fully occupied with the firm of Messrs. Guest, Keen and Nettlefolds. About 1880 he became a Director of the Birmingham and Midland Bank, and it was largely as a result of his efforts that this bank was converted into the London and Midland Bank in 1891, and amalgamated with the City Bank in 1898, becoming the London, City and Midland Bank. In this year Mr. Keen was elected Chairman of the Bank, which office he held until 1908, when he retired on account of his health. His death took place at his residence at Edgbaston, Birmingham, on 8th February 1915, at the age of eighty.

On the occasion of the Jubilee Meeting of this Institution being held in Birmingham in 1897, Mr. Keen acted as Chairman of the Reception Committee, which ensured the success of the Meeting. He took an active part in public work, and was a Justice of the Peace for Staffordshire and a Governor of the University of Birmingham. He was elected a Member of this Institution in 1869, a Member of Council from 1891 to 1897, and from that date to 1911, when he resigned, he held the office of Vice-President. He was also a Vice-President of the Iron and Steel Institute.

John Edward Livsey was born at Todmorden, Yorkshire, on 9th February 1856. He served his apprenticeship from 1872–1875

with Lord Brothers, machine makers, and Messrs. J. Barker and Sons, millwrights and engineers, Todmorden. In the winter of 1875–1876 he attended science classes at the South Kensington Science Schools, and from 1876–1882 was engaged by the Science and Art Department of the Schools as draughtsman and model-maker. In 1882 he was appointed demonstrator in Mechanics and Mathematics, and placed on the permanent staff of the Normal School of Science and Royal School of Mines. Mr. Livsey was for many years Chairman of the Electric Lighting Committee and an active member of the Battersea Borough Council. He had an inventive mind, and amongst other ideas devised, in 1904, a combined rifle back-sight and wind-gauge. His death took place in London on 30th March 1915, at the age of fifty-nine. He was elected a Member of this Institution in 1886.

John Bruce King Macbeth was born at Greenock on 15th September 1858, being the son of the late Norman Macbeth, R.S.A., and brother of the late Norman Macbeth,* *Member*, with whom he entered into partnership in 1882, under the name of Macbeth Brothers and Co., as machinery agents and engineers. Branches were subsequently established in Bombay and Calcutta. His death took place in London, on 9th December 1914, at the age of fifty-six. He was elected a Member of this Institution in 1888.

James Maurice Newall was born in London on 2nd February 1867. He was educated, from 1873 to 1879, at Holy Trinity National School, Plaistow, and from 1883 to 1884 attended evening courses at the Andersonian College, Glasgow. He served his apprenticeship from 1879 to 1883 with Messrs. Lester and Perkins, engineers, Royal Albert Dock, and from 1883 to 1885 with Messrs. D. and W. Henderson and Co., shipbuilders and engineers, Glasgow. In 1886 he went to sea as junior engineer, and received in 1889 a 2nd Class Board of Trade certificate and a 1st Class in 1891. From 1894 to 1896 he sailed as chief engineer. He was engaged during the three following years as foreman engineer to Messrs.

* Proceedings 1914, page 352.

A. W. Robertson, Royal Albert Docks, and as engineering manager from 1899 to 1901 to Messrs. R. and H. Green, shipbuilders and engineers, Blackwall Yard, London. In 1901 he became assistant superintendent engineer for the American Line at Liverpool, and subsequently held a similar position with the White Star, American, and Dominion Lines. In July 1914 he was appointed head of the Repairs and Costs Department of the above Companies. Among his inventions may be noted an electro-mechanical instrument for registering the running of the engines, and a door-catch for rendering doors burglar-proof. He was also interested in the design of a boat-lowering gear. His death took place at Liverpool on 20th December 1914, in his forty-eighth year. He was elected a Member of this Institution in 1904; he was also a Member of the Institute of Marine Engineers.

JOHN McCLURE CALDWELL PATON was born at Wednesbury, Staffs, on 28th April 1852. After being educated at public schools at Newport (Salop) and Atherstone, he was apprenticed in 1867 to the firm of Manlove, Alliott and Co., of Nottingham. On the completion of his apprenticeship he spent some time in a sugar refinery in Liverpool, working both in the laboratory and the refinery, where he obtained a thorough knowledge of the manufacture of sugar in this country. For some years he then travelled in the Dutch East Indies, where he represented the firm of Manlove, Alliott and Co. with considerable success. In 1879 and 1880 he visited the Australian Colonies and British India, and in the following year, after a further visit to Australia, he returned to England, being appointed general manager of Messrs. Manlove, Alliott and Co.'s Works in Nottingham. In 1884 he was admitted to the firm as a partner, and in 1888, when it was converted into a limited company, he was appointed managing director in conjunction with Mr. Alliott. His name was specially associated not only with the manufacture of sugar machinery, but also in connexion with works relating to Sanitation and Public Health. Mention may be made of the firm's design of the Washington Lyon steam disinfector, in which the improvements effected by Mr. Paton have resulted

in the disinfector being considered the standard of what such an apparatus should be. His death took place, after a short illness, at Nottingham, on 10th April 1915, in his sixty-third year. He was elected a Member of this Institution in 1877; he was also a Member of the Society of Chemical Industry, and of the Royal Institution of Holland, while residing in the Dutch Colonies.

Frank Henry Pearson was born at Hull, on 24th November 1844. He was educated at the Naval School, Gosport, and in Germany. He served an apprenticeship of four years in the Works of Messrs. R. Morrison and Co., of Newcastle-on-Tyne, and afterwards was engaged as draughtsman. He then joined the firm of Byrne, Humphrys and Co., engineers and shipbuilders, of which he eventually became a partner in 1868, carrying on the business for five years as Humphrys and Pearson. On its being turned into a limited company he stayed on, as one of the managers and secretary, until 1875. He then, for some two years, practised in London and Newcastle as consulting engineer, returning to Hull as secretary of Earle's Shipbuilding and Engineering Co., Ltd., with which company he stayed as assistant general manager till its winding up in 1900, when he started once more as consulting engineer, naval architect, and surveyor. His death took place at Hull on 8th February 1915, at the age of seventy-one. He was elected a Member of this Institution in 1884; he was also a Member of the Institution of Naval Architects and the author of "The Early History of Hull Steam Shipping, 1821 to 1850."

James Cartmell Ridley was born at Newcastle-on-Tyne on 31st January 1844. He served an apprenticeship of five years with Messrs. Robert Stephenson and Co., and after a short time at sea, became rolling-mill manager of Messrs. Palmer and Co., Ltd., Jarrow-on-Tyne. He held this post for a few years, eventually becoming partner in the firm of Bell, Ridley and Bell, Walker Rolling Mills, which firm dissolved partnership in 1877. Some four years later, Mr. Ridley established the Swalwell Steel Works, which he ran for about thirty years. His death took place at Newcastle-on-Tyne, on 27th December 1914, in his seventy-first year. He was

elected a Member of this Institution in 1879; he was also an original Member of the Iron and Steel Institute.

GEORGE PATRICK ROBERTSON was born at Blairgowrie, Scotland, in 1869. He was educated at Rattray School, near Blairgowrie, from 1875 to 1883, when he went to Daniel Stewart's College, Edinburgh, until 1886. He received his technical education from 1886 to 1891 under John Lockie, Leith, and at Heriot Watt College, Edinburgh, where he attended evening classes, and during that time he served his apprenticeship at Bertrams, Ltd., Edinburgh. In 1891 he joined the Woodside Electric Co., Glasgow, and was for a few months electrical engineer and 6th engineer on S.S. "Nebraska," plying between Glasgow and New York. From 1892 to 1896 he was engineering assistant on the Amo Tea Estate, Sylhet, and from 1896 to 1903 manager of Sylghat Tea Estate, then of Silloah, and finally of New Dooars Tea Estates. In 1903 he became engineer to the Darjeeling Municipality, and was holding this post at the time of his death, which took place on 20th January 1915, in his forty-sixth year, as the result of a boat accident on the River Rungeet. Mr. Robertson read a Paper on the History, Construction, and Mechanics of Surface Drains in Darjeeling, at a Meeting of the Calcutta Section of this Institution, on 19th March 1913. He was elected an Associate Member in 1911.

Professor HENRY ROBINSON was born in London on 22nd March 1837, and received his training for the engineering profession in the Applied Science Department of King's College, London, of which he became a Scholar and an Associate. He was afterwards, for a few years, on the staff of Sir William G. (the late Lord) Armstrong at Elswick, and then commenced independent practice as a civil engineer in Westminster, which he followed for upwards of forty years. During this time he carried out many important works, including railways, water supply, sewerage and electric lighting, an example of the latter being the successful installation of St. Pancras. He took an active part in promoting the distribution of energy in towns by hydraulic power, compressed air, and

electricity, and carried out the first public hydraulic scheme in this country at Hull, where an Act was obtained for laying mains in the streets. Professor Robinson occupied the Chair of Civil Engineering at King's College, London, from 1880 to 1902, when he was elected Emeritus Professor. He contributed much to engineering literature of the day, being author of important works on "Hydraulic Power and Hydraulic Machinery," "Sewerage," and "Sewage Disposal." His death took place in London on 24th March 1915, at the age of seventy-eight. He was elected a Member of this Institution in 1874; he was also a Member of the Institution of Civil Engineers, the Institution of Electrical Engineers, a Fellow of the Surveyors' Institution, the Royal Sanitary Institute, and Past-President of the Society of Engineers.

William Wasteneys Smith was born at Conisborough, near Doncaster, on 10th January 1838. He was educated privately, and served his apprenticeship with Messrs. Dodds and Sons, locomotive builders, etc., of Rotherham. In 1859 he joined the Royal Navy as assistant engineer, and was for four years on H.M.S. "Bacchante," which was stationed at that time in the Pacific. In 1866 he resigned from the Navy, and having secured an appointment with Messrs. Waring Bros., railway contractors, he was sent out by them to Portugal, where he acted as civil engineer on the railways which they were constructing. Returning to England in 1868, he was appointed Inspector of Bridges to the Russian Government, and was sent to Messrs. Hawks, Crawshay and Co.'s Works, Gateshead-on-Tyne, which at that time were constructing wrought-iron girder bridges for the Transcaucasian Railways. In 1872 he commenced business on his own account as consulting engineer, etc., at Newcastle-on-Tyne, which is now carried on by his sons, under the name of Wasteneys Smith and Sons. He invented the stockless anchor, which is largely adopted by the British and Foreign Governments, and also by the Mercantile Marine. Many of the present battleships, battle cruisers, etc., of the British Navy carry these anchors. His death took place at his residence, Backworth Hall, near Newcastle-on-Tyne, on 22nd July

1914, in his seventy-seventh year. He was elected a Member of this Institution in 1881.

William Swinburne was born at Newcastle-on-Tyne, on 2nd November 1863. He was educated at the Royal Grammar School in the same city, and received his technical education at the Schools of Science and Art, Elswick Mechanics' Institute. From 1878 to 1884 he served his apprenticeship at the engineering works of Messrs. Henry Watson and Sons, Newcastle-on-Tyne, and in 1884 became engaged at Sir W. G. Armstrong's Elswick Works. He left this firm in 1885 to go to Messrs. J. Abbot and Co., Gateshead, with whom he remained until November 1886, when he went to Australia with hydraulic machinery for the Melbourne Gas Works. After this machinery had been erected, he entered the Melbourne Hydraulic Power Co., Ltd., as outside and inspecting engineer, becoming assistant manager in 1892, manager and engineer in 1900, and eventually managing director, a position which he held at his death. In addition, he was managing director of the Colonial Gas Association, and a director of the firm of Johns and Waygood, and of several smaller gas companies. He was also a member of the firm of John Coates and Co., and Messrs. G. and W. Swinburne. His death took place at Hawthorn, Melbourne, on 13th January 1915, in his fifty-second year. He was elected a Member of this Institution in 1901.

Engineer-Captain Charles Gerald Taylor, M.V.O., R.N., was born at Ruabon, North Wales, on 8th May 1863. He was educated at the Grammar School at Ruabon, after which he went to Portsmouth Dockyard as engineer student in H.M.S. "Marlborough" from 1879 to 1885. In the latter year he joined the Royal Naval College, Greenwich, and on 1st July 1886 was granted a commission as assistant-engineer, with seniority. He received an appointment to H.M.S. "Carysfort," Mediterranean Fleet, in May 1887, and remained on that ship until May 1890, when he was invalided home with malarial fever. On 30th October of the same year he joined H.M.S. "Gossamer," remaining until January

1891, when he went to H.M.S. "Impérieuse," China Station, having been promoted to engineer, with seniority in 1890. He was next appointed to H.M.S. "St. George" in June 1894, and after three months was transferred to H.M.S. "Banshee." A year later he joined H.M.S. "Quail," and remained in that ship on her transfer to the North America and West Indies Station. In February 1898 he was appointed to H.M.S. "Renown," Halifax Dockyard, and in December 1900 became Chief Engineer, with seniority. He returned to England in March 1903, and in April of that year he joined H.M.S. "Aurora," taking, under the new nomenclature, the rank of Engineer-Lieutenant, with seniority 1st September 1890. In August 1904 he was transferred to H.M.S. "Racer," Royal Naval College, Osborne, being at the same time a Member of the Committee on the Extension of the Training of Officers' New Scheme. In this capacity he received the commendation of the Lords of the Admiralty for the work done by the Committee, and was promoted to the rank of Engineer-Commander on 30th December 1904.

He went to sea again in September 1907 on board H.M.S. "Cumberland" (cadets' training ship), and in April 1908 was appointed to H.M.S. "Espiègle," Royal Naval College, Dartmouth, where his work once more received the special recognition of the Lords of the Admiralty. On 10th February 1911 he was made a Member of the 4th Class of the Royal Victorian Order. In March 1911 he was appointed to H.M.S. "Superb," in the Home Fleet, being promoted to Engineer-Captain, with seniority on 7th February 1912, in which capacity he was retained by the Admiralty for the new scheme of training officers for the Royal Navy. In October 1912 he joined H.M.S. "Hercules," additional for service on the staff of the Vice-Admiral Commanding the Second Battle Squadron, and in August of the following year was made Engineer-Captain in Command, Royal Naval College, Keyham.

In September 1914 he joined the staff of the Vice-Admiral Commanding the First Battle-Cruiser Squadron, and was present in the capacity of engineering expert and adviser to Vice-Admiral Sir David Beatty in all subsequent services. It was on board

H.M.S. "Tiger," in the engagement of 24th January 1915, in the North Sea, that he met his death by gun-fire, in his fifty-second year, being the only officer to lose his life on the occasion. He was elected a Member of this Institution in 1900.

JOHN SEATON WARBURTON was born at Hipperholme, Yorkshire, on 11th July 1848. He received his technical education at the School of Mines, Jermyn Street, London, and served an apprenticeship for two years in the works of John Crossley and Co., machine makers, Halifax, after which he was for one year in the office of W. Brierley, patent agent, Halifax, and for five years in the drawing-office—engineers' department—of Messrs. W. Pile and Co., marine engineers, Sunderland. He then became engaged on the erection of blast-furnaces at Messrs. T. Richardson and Co.'s Works, West Hartlepool, where he stayed for one year, until the completion of the works. He next started in business on his own account in Queensland, where he was engaged in the introduction of machinery for goldfields and public works, and by the Queensland Government, for three years, in inspecting machinery for the South Brisbane Graving Dock. On his return to London he was appointed, in October 1879, manager to Messrs. Le Gros, Mayne, Leaver and Co., proprietors of the Ingersoll Rock Drill, and on leaving them became engineer to Messrs. Brooks, Shoobridge and Co., Grays, Essex, cement manufacturers, with whom he stayed till 1892, when he joined the British Xylonite Co., Manningtree, as engineer. Mr. Warburton retired from business in 1903. His death took place on 18th October 1914 at West Kensington, London, at the age of sixty-six. He was elected a Member of this Institution in 1881.

SAMUEL BARTON WORTHINGTON was born at Stockport on 14th December 1820. His father having removed to Manchester, he was educated at the private schools of the Rev. Edward Hawkes, M.A., and the Rev. J. R. Beard, D.D., in that city. At the former he acquired a knowledge of the classics which was a pleasure to him through life, and at the latter a knowledge of mathematics, chemistry, and geology, not often to be obtained in

the schools of that day. In September 1836 he was articled to Joseph Locke, George Stephenson's pupil and assistant, who very soon afterwards removed from Liverpool to London. During his pupilage he was engaged upon preliminary surveys and contract drawings and designs for many of the early railways for which Locke was engineer or otherwise interested, including the Lancaster and Preston, London and Southampton, Eastern Counties, Glasgow, Paisley and Greenock, Grand Junction, Shrewsbury and Wolverhampton, Stone and Rugeley, Preston and Wyre, Southampton to Gosport, and Carlisle to Glasgow. On 19th August 1840 he accompanied Mr. Locke on his journey from Southampton via Havre and the River Seine to Paris to start the works of the Paris and Rouen Railway. The party consisted of Mr. and Mrs. Locke, Mr. (afterwards Sir William) and Mrs. Tite, Mr. Reed, Secretary of the London and Southampton Railway (afterwards Manager of the Paris, Rouen and Havre Railway), G. Neumann (Locke's pupil, to be resident engineer on the Paris and Rouen Railway), and himself. He was employed on the construction of the Paris and Rouen Railway until its opening on 1st May 1843, after which he was for about a year one of the three resident district engineers in charge of the line. In June 1844 Locke recalled him to England to take up the position of resident engineer on the construction of the southern half of the Lancaster and Carlisle Railway, for which Locke and Errington were the engineers. On the opening of the line for traffic, from Lancaster to Kendal on 17th September 1846, and to Carlisle on 22nd December 1846, he became engineer to the Lancaster and Carlisle Railway Co., with charge of the line and rolling stock, a position which he held until the Lancaster and Carlisle Railway was leased by the London and North Western Railway Co. in 1859.

The construction of the Caledonian Railway from Carlisle to Glasgow, on the original trial levels of which he had been engaged while still a pupil, was in 1847 approaching completion, and it is of interest to note that on 27th November of that year he travelled by a special express from London to Beattock (the northern end of the open line of the Caledonian), driving the engine himself

from Lancaster to Carlisle. The time from Preston to Carlisle (90 miles) was 2 hours 31 minutes. While engineer to the Lancaster and Carlisle Railway Co. he had also been engineer to the Carlisle Joint Station Committee.

On the absorption of the Lancaster and Carlisle Railway Co. he was appointed engineer of the northern division of the London and North Western Railway, and in 1863 removed to Manchester. This position he held until his retirement from the railway service in 1885. The little dwarf engine "Carlisle," built by George England and Co., London, which, with the little four-wheeled inspection saloon, was such a familiar sight on the Lancaster and Carlisle Railway and the northern division of the L. and N. W. R. for many years, was broken up on his retirement.

It is worth noting that on 1st July 1837, young Worthington, who had then completed ten months of his pupilage, rode on the "Zamiel," the first of the two engines which took the directors' train from Warrington to Birmingham prior to the opening of the line for public traffic on 4th July. On the opening day he rode on the footplate of the engine drawing the directors' train from Birmingham to Liverpool with Locke, who himself drove the engine for part of the journey, attaining a speed of 45 miles per hour for a short distance. He also rode on the first engine which took a train through the Woodhead Tunnel of the Manchester and Sheffield Railway, of which Locke was engineer, on 22nd December 1845.

After his retirement from the charge of the northern division of the L. and N. W. R. in 1885, he practised for some years as a consulting engineer in Manchester, and for nine years devoted his valuable experience and sound common sense to the service of his fellow-citizens as a Member of the Corporation of the City of Manchester. His death took place at his residence at Bowdon, Cheshire, on 8th February 1915, at the age of 94. He was elected a Member of this Institution in 1860. He was also a Member of the Institution of Civil Engineers.

INDEX.

1915.

January–June.

Photo-micrographs of the 5 Hammered Steel Bars as received from the forge, also that of Fig. 6, after annealing. × 250 diameters.

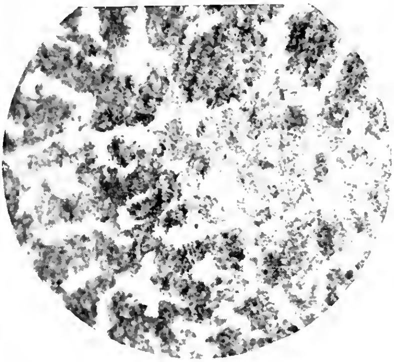


Fig. 2. *0·64% Carbon. 2·68% Cobalt.*

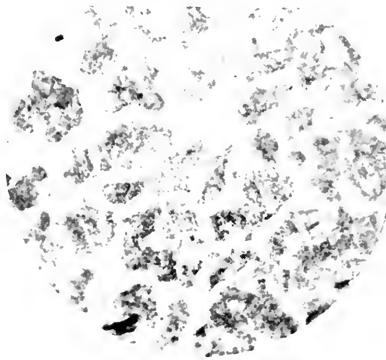


Fig. 3. *0·62% Carbon. 5·50% Cobalt.*

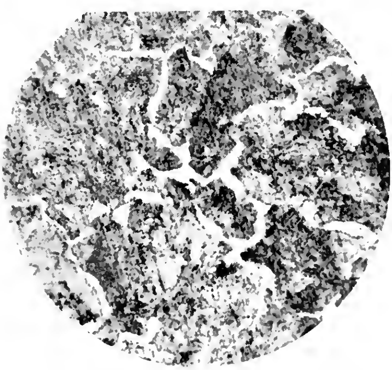


Fig. 4. *0·84% Carbon. 11·18% Cobalt.*

Fig. 5. *0·93% Carbon. 16·97% Cobalt.*

Fig. 6. *Annealed.*
0·00% Combined Carbon.
0·93% Graphite. 16·97% Cobalt.

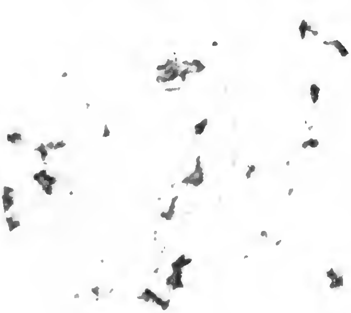
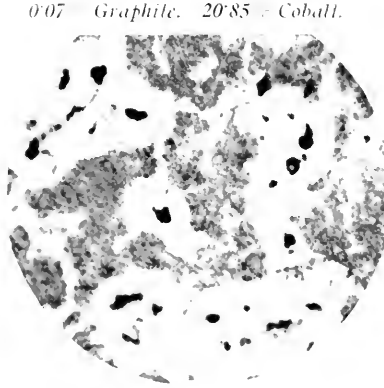
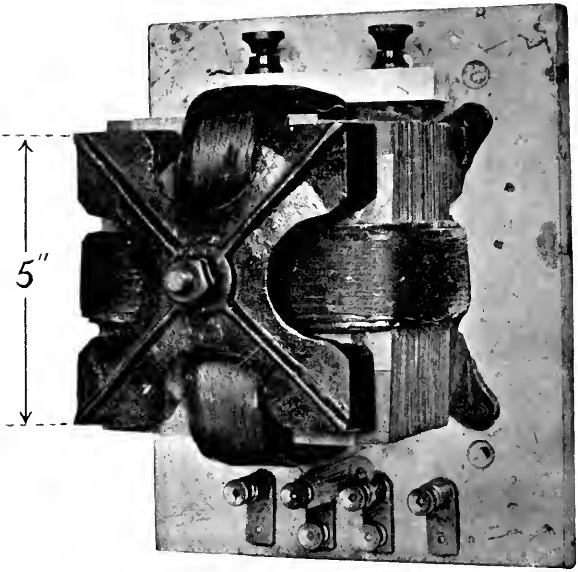


Fig. 7.
0·72% Combined Carbon.
0·07% Graphite. 20·85% Cobalt.



First Transformer of Low-Hysteresis Silicon-Steel (Hadfield).
Made in Oct. 1903. *Weight 30 lb.*



Special Soft Steel Cap (Hadfield) for 4⅞" Armour-Piercing Shell.

Before Firing. *Front.* *After Firing* *Back.*

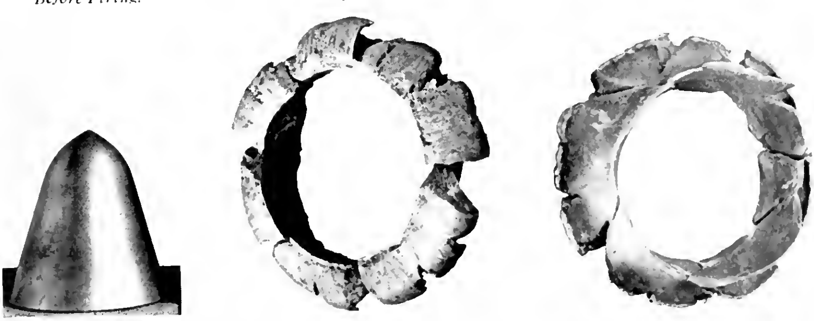
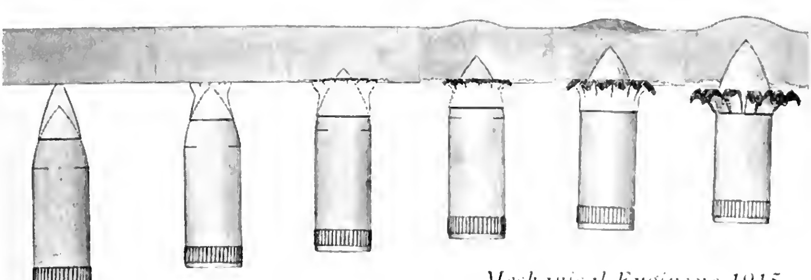


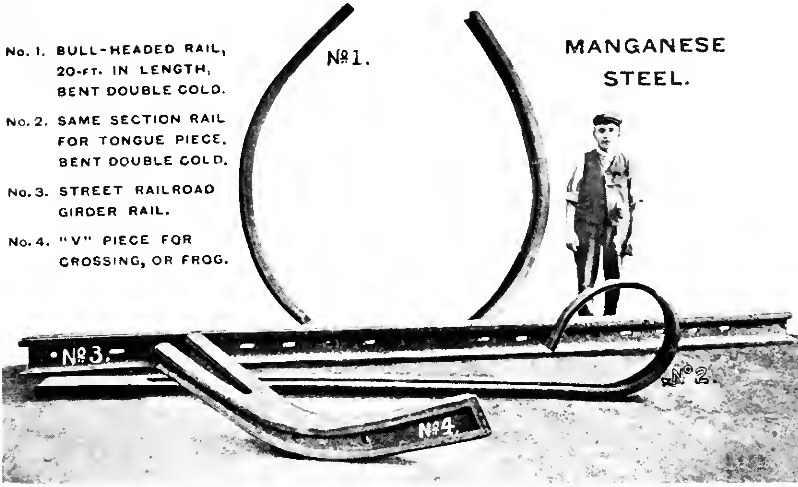
Diagram showing Cap Action on Armour-Piercing Projectiles.

It will be seen that the cap is eventually forced back and at the same time stretched until it assumes practically the calibre of the projectile.

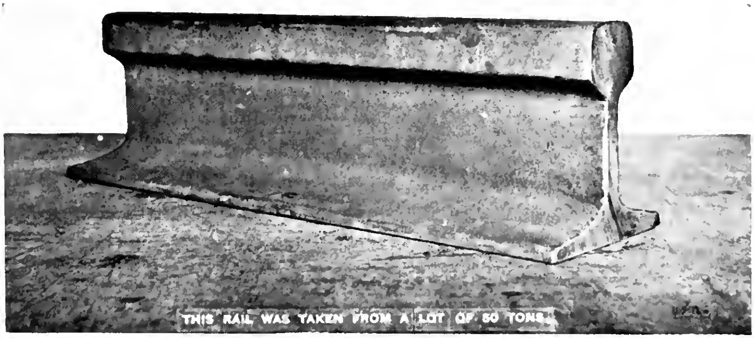


Mechanical Engineers 1915.

Manganese-Steel.
Cold Bending Tests.

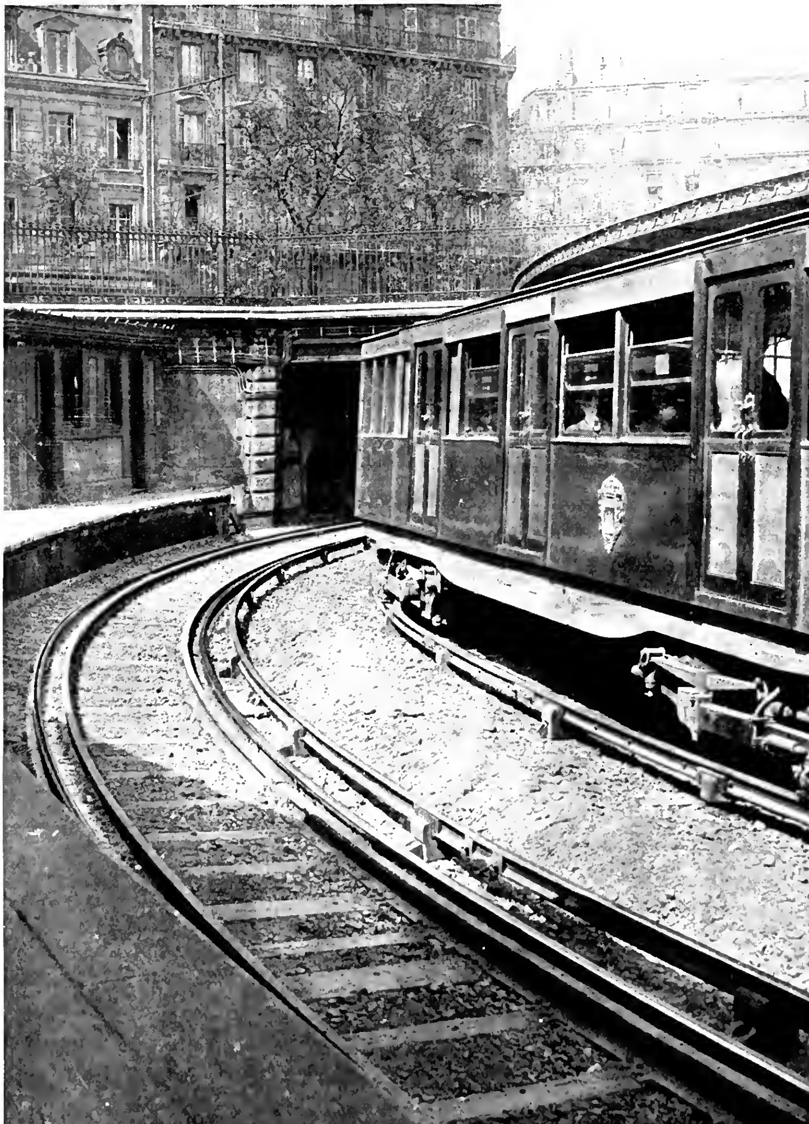


Rail, 100 lb. per yard.
Metro. R., Paris (Schneider).



Rail.

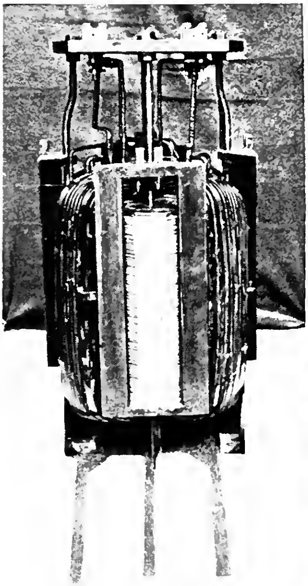
Manganese-Steel Rails.
(110 lb. section, about 40 ft. in length.)
Rolled in 1907. Metro. R., Paris. (Bastille Station.)



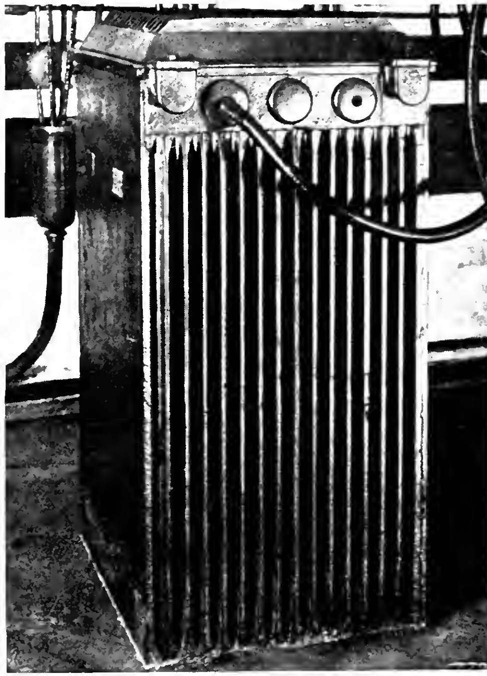
After about two years in severe curve work, the total wear being about 1 to 1½ mm. It is estimated that the rails will remain in service for six to seven years before being worn out, whereas ordinary steel rails wear out and have to be replaced in less than a year.

40 Kw. Transformer, made in June, 1905.

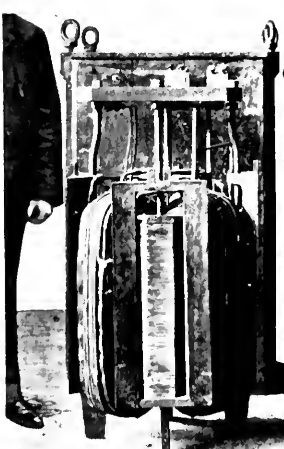
Before being put into use.



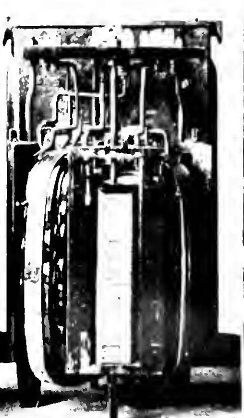
Transformer after 7 years' continuous service.



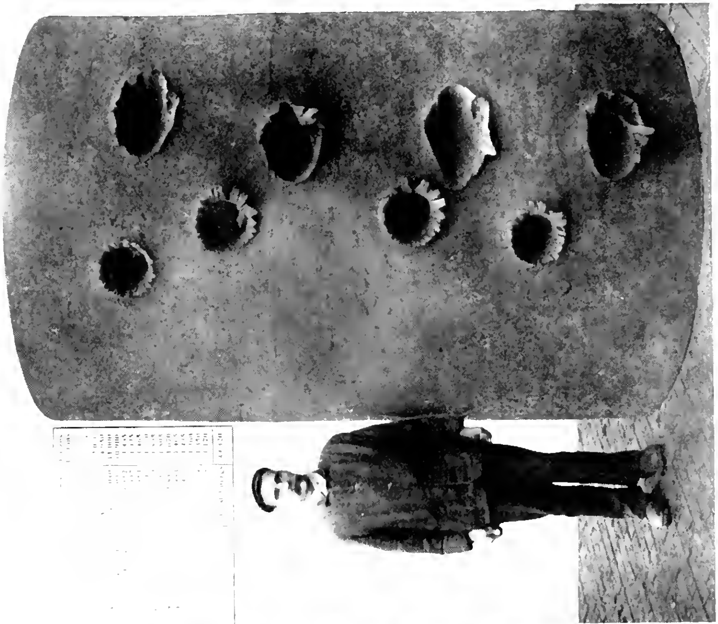
40 Kw. Transformer made of best Transformer Iron.



60 Kw. Transformer made of Low-Hysteresis Steel, June, 1906.

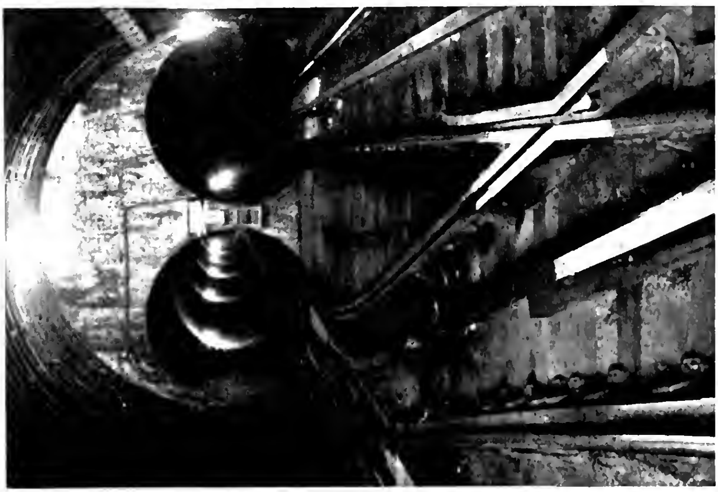


Transformer after 6 years' continuous service.



Ammunition Tube. "Era" Steel.
7-inch in thickness, after being attacked.

15-inch capped "Heclon" Armour-piercing Projectile after perforating a 15-inch hard-faced armour plate of the latest type.



Manganese-Steel Crossings.
British Museum Station, C.L.R.
12 years old. Total Traffic 600 million of tons.
Estimated to last 2 or 3 years longer.

7/9/15